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**Fastening systems to concrete sleepers – comparison of the operating characteristics of fastening systems: SB and W14**

**Abstract:** The paper presents a comparative analysis of the most important operating characteristics of fastening systems type SB and W14. A review of the applied elastic fastening systems for concrete sleepers was shown. The results of laboratory tests carried out in accordance with the applicable European standards PN-EN 13481 and EN 13146 series have been described synthetically and other operational characteristics such as track gauge regulation, stress control, possibility of track extension and complete of elements of fastening system in the production concrete sleeper plants.

**Keywords:** Fastening system SB; Fastening system W14; Laboratory research of fastening system; Technical specifications for interoperability

The paper presents a comparative analysis of the most important operating characteristics of fastening systems type SB and W14. A review of the applied elastic fastening systems for concrete sleepers was shown. The results of laboratory tests carried out in accordance with the applicable European standards PN-EN 13481 and EN 13146 series have been described synthetically and other operational characteristics such as track gauge regulation, stress control, possibility of track extension and complete of elements of fastening system in the production concrete sleeper plants. Technical Specifications of Interoperability 1299/2014 [10] for the subsystem rail infrastructure in the European Union classifies the fastening system as one of three interoperability components. In compliance with above, the fastening must meet the requirements of the above-mentioned regulation and effective European standards from the series PN-EN 13481 [9] and PN-EN 13146 [8]. Such requirements enable the standardization of operational parameters of individual solutions of fastening systems and force European manufacturers to maintain high standards of their products, and thus fulfill the user's expectations.

The basic, currently used in Poland fastening system for prestressed concrete sleepers is SB type fastening (fig. 5). The concept of elastic fastening type SB3 was established in 1979 at the Central Railway Technology Research and Development Center (since 1987 the Scientific and Technical Center of the Railway and since 2010 the Railway Institute). In the following years, after many researches and analyzes, it was verified that the SB4 has better parameters due to the lower contact stresses in the insole and the more favorable stress state [1]. Currently, modifications of the SB type fastening system with SB4, SB7 and SB8 clamps are used.

World markets of fastening systems were dominated by W-type fasteners (Figure 6), e-Clip (Figure 1a) and FASTCLIP (Figure 1b).

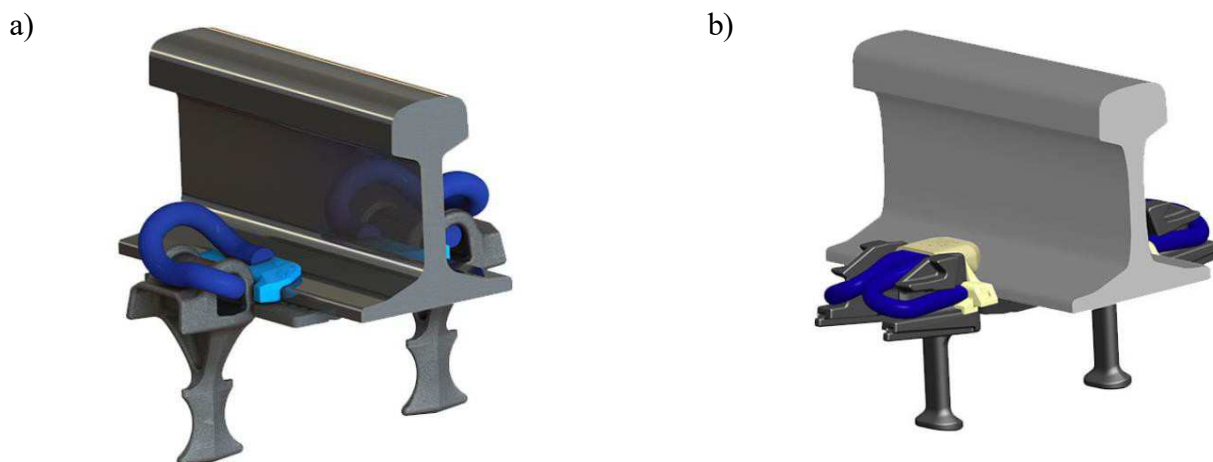
On the German railways, W14 type fastening is the most widespread with a springy clamp type Sk1 14, on British railways PR Clip and FASTCLIP are commonly used, whereas on French railways the most popular are spring fastenings RN and Nable type (Fig. 2).

However in the Swedish railways, a FIST type fastening system was introduced (Figure 3). This system is currently used as standard in railway networks in South Africa, Zimbabwe and

Australia. In this solution, the rail fastening element is unusually attached to the underlay on its aside surface.

In this article, the SB and W14 type fastening system widely used in Poland was compared. The W14 fastening can be an alternative to SB, due to its advantages related to production, transport of material for construction and operational parameters.

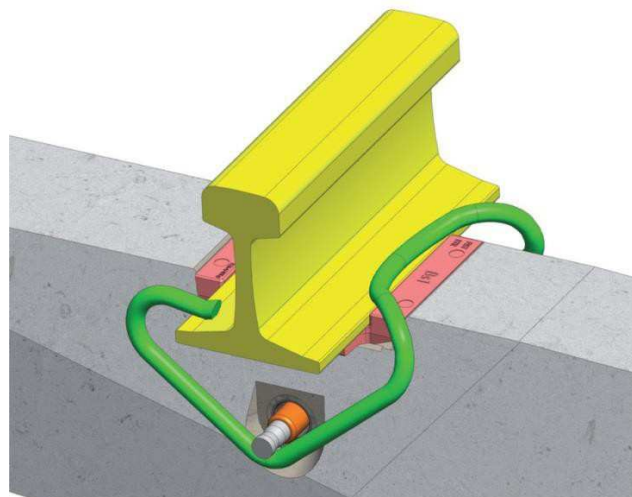
The classic railway pavement is a multi-layer system consisting of rails, fastening systems, sleepers and ballast. Each subsequent layer has a larger surface area which results in a change in the stress created at the interface between the wheel and the rail. Vertical, transverse and longitudinal forces act on the railway track. Fig. 4 shows the arrangement of forces system on the railway surface.



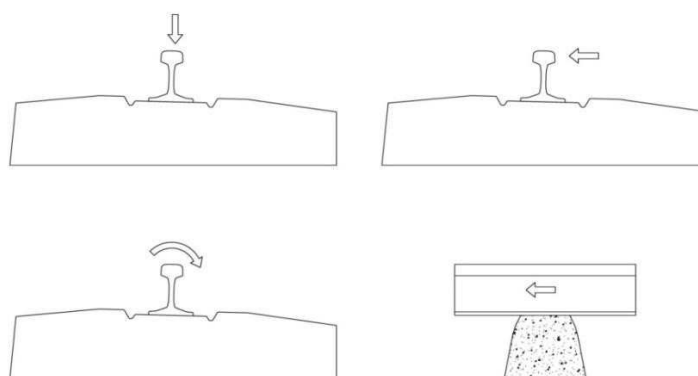
1. Fastening systems: a) e-clip, b) Fastclip Source: [15]



2. Nable type fastening systems. Source: [15]



3. FIST type fastening systems. Source: [14]



4. Arrangement of forces operating a railway track  
Source: [12]

The selection of the fastening system and components entering the entire node is crucial in the correct and reliable functioning of the track. It is necessary to use springing feet with the required clamping force and pads of the railing with such selected stiffness, to minimize its impact on the ballast degradation, and thus goes the entire pavement, as well as the reduction of vibrations caused by the operation of the railway track. The choice of stiffness of the spacer should provide damping of dynamic loads. Due to ensuring the sagging of the rail on the flexible spacer, the stresses are distributed over a greater number of sleepers. Which means that the shoulder pad also has the ability to distribute loads.

The fastening system is a set of mutually cooperating elements that enable fastening of the rail to the support (in particular the foundation) in the required position, while allowing (flexible system) the movement of the rail in the intended range (vertical, horizontal and longitudinal displacements). It is worth recalling that the fastening system must fulfill the following functions, i.e. (see also [6]):

- transfer of forces from the rails to the supporting element (eg underpad),
- damping of vibrations and strokes caused by the movement of rail vehicles,
- maintaining the proper track width,
- maintaining a proper cross-slope of the rails,
- ensuring adequate pressure of the rail to the supporting element

in order to limit longitudinal displacements,

- providing electrical insulation between rail tracks,
- ensuring adequate elasticity of the track in the horizontal plane (resistance to rail rotation with respect to the underlay),
- ensuring adequate elasticity of the track in the vertical plane (resistance to rail torsion with respect to the longitudinal axis).

According to [10], fastening systems must archive the following standard requirements:

- The longitudinal resistance of a single fastening must be at least 7 kN in the case of conventional rail, while for high-speed rail (speeds over 250 km / h) the longitudinal drag must be greater than 9 kN. This value can not be reduced by more than 20% after 3 000 000 cycles of a typical arc load. The same requirements apply to the clamping force in the fastening system.
- vertical stiffness can not be reduced by more than 25% after the effect of repetitive loads at 3,000,000 load cycles and unloading.

Such dependencies must be archive at a typical load adequate to the maximum axle load, which, according to design assumptions (is to withstand the fastening system).

A set of researches confirming the usefulness of the fastening system in the trans-European rail system is contained in European standards [9,8]. Complete research includes:

- checking the longitudinal resistance,
- checking the resistance to torsion,
- checking the suppression of impact loads,
- checking the vertical stiffness of the static fastening system,
- checking the vertical stiffness of the dynamic fastening system,
- checking the effects of repetitive loads,
- resistance check,
- checking the consequences of difficult environmental conditions,
- checking the pressure of the rail against the foundation,
- checking the influence of dimensional tolerances on the track width,
- checking the overall dimensions,
- checking the anchored elements of the fastening system.

After carrying out a set of researches in accordance with the binding provisions, the fastening system and all its components must not show any wear (usage), scratches or cracks - this also applies to elements concreted in a prestressed concrete foundation.

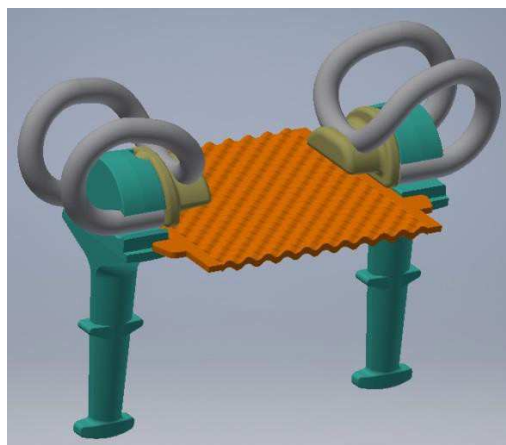
In addition, the fastening system should be chosen to the requirements for track strength for vertical, horizontal and longitudinal loads are met.

SB fastening system is designed for prestressed concrete sleepers type PS-94, PS-93, PS-83. The SB attachment consists of:

- 2 elastic feet type SB4, SB7 or SB8,
- rail padding type, e.g. PKW, PWE, PKV,
- 2 insulating inserts, e.g. WKW, WIW,
- 2 anchors, eg SB3/3, SB3/P, SB3 /4 or other types approved for use.

Fig. 5 shows an example SB type fastening system.

The spheroidal iron anchors in the SB system are permanently mounted in the prestressed concrete foundation. They are installed in a distance depending on the width of the foot of the rail used. In each base there are four anchors - two for each fixing point. Between the anchors, under the rail, a railing is placed, and then insulating inserts. The rail is secured by means of anchors with the help of the SB type spring clamp. However, it is not possible to pre-assemble the fastening system in the production plant, time-consuming assembly at the construction site is necessary from elements usually delivered from another supplier.



5. An exemplary configuration of the SB type fastening system

Source: own archive

A completely different system is the fixing of type W14 fixation. It consists of from the following elements:

- 2 dowels Sdü 25,
- 2 screws with SS35 / Uls7 washers,
- 2 elastic feet, e.g. Skl 14, Skl 14RT,
- 2 angular guide plates, eg Wfp 14K 12 / Wfp 14K 12NT type,
- rail liner, e.g. Zw 900, Zw 900 NT, Zw687a.

Fig. 6 shows an example of the W14 type fastening system.

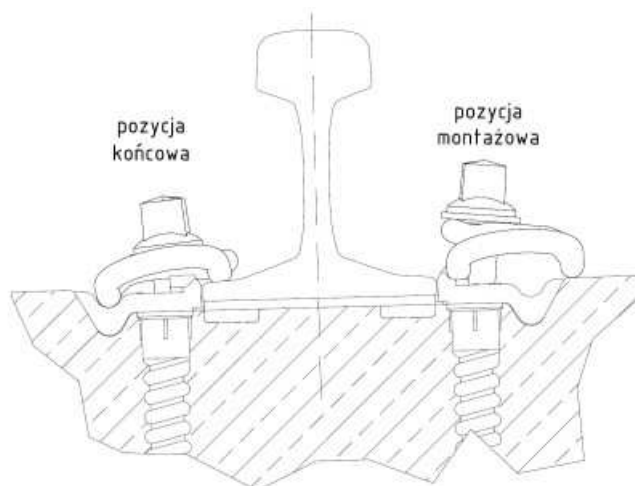


6. W14 type fastening system

Source: own archive

The W14 type fastening was designed for use on prestressed concrete sleepers, on which the padding zone was formed accordingly. The angle guide plate Wfp is used to ensure that the rail is maintained in the required position in such a way that the load is transferred directly to the concrete foundation in a way that protects the screw against bending and shear. The rail is placed on an elastic shoulder pad placed on the surface of the underlay. Skl 14 shape clamp is similar to the shape of a letter “W” - provides system elasticity and excludes overloading that can lead to plastic deformation. In addition, the center loop protects the rail against tilting. The system also

protects the rail against excessive rotation, eg in the case of rolling stock on arcs with small radii through the middle loop of the elastic clamp. In this way, any of permanent deformation of the elastic arms in the feet is ensured. Clamps in the fastening system W14 have two positions in the attachment during production process - building cycle. The fixing is mounted in sleepers in the so-called "Assembly position" in the production plant whereas after laying them on the foundation, the clamp is moved to the foot of the rail and then tightened with the required moment. Fig. 7 shows the Skl 14 elastic leg in the assembly position and in the correct position. The use of a screw solution prevents spontaneous detachment of the elastic legs during track use.



7. The method of assembling the elastic leg Skl 14 in fixing W14  
Source: own archive

In 2015, tests of the SB-TT-K3 and SB-TT-K4 fastening knots and also W14TT / 60E1 and W14TT / 49E1 with pre-tensioned undercoat for compatibility with the provisions of the standards PN-EN 13146: 2012 and PN-EN 13481: 2012, were carried out in the Laboratory of Building Materials and Structures of the Cracow University of Technology.

Type designations "TT" and "K3" and "K4" refer to manufacturers of anchors and insulating inserts, they mean a specific configuration launched by Track Tec. The results of these tests are presented in [1,2] papers and summarized in Tab. 1.

**Tab.1** Results of laboratory researches of SB and W14 type fastening systems

Parameters	Fastening system	
	SB	W14
Dynamic vertical stiffness	61,2 MN/m	100,4 MN/m
Static vertical stiffness (before cyclic loading)	41,5 MN/m	86,6 MN/m
Static static stiffness (after cyclic loading)	50,2 MN/m (switch <25%)	104,6 MN/m (switch <25%)
Longitudinal resistance (before cyclic loading)	21,5 kN	14,0 kN
Longitudinal resistance (after cyclic loading)	18,9 kN (switch <20%)	13,2 kN (switch <20%)
Clamping force (before cyclic loading)	19,8 kN	19,7 kN
Clamping force (after cyclic loading)	18,3 kN (switch <20%)	18,6 kN (switch <20%)
Torsion resistance	1,15 kNm/1 <sup>0</sup>	1,27 kNm/1 <sup>0</sup>
Suppression of impact loads	49,30%	47,30%

Below we will present the results “synthetically”, limited only to the tests carried out for the 60E1 bus.

1. Both tested fastening systems meet the requirements of the relevant standards. This also applies to other features not included in the table. 1 (eg electrical insulation, impact of difficult environmental conditions),
2. Static and dynamic stiffness of the SB system is clearly lower than W14 - static stiffness, both before and after the cyclic loading of the tested SB system is about twice lower than the tested W14 system. This is due to the selection and use of a rail pad with a given static stiffness. Changing the spacer, which has a dominant effect on the stiffness of the entire system will change the stiffness of the fastening node,
3. Longitudinal resistance is greater by about 40 - 50% than in the case of the W14 system. It should be noted, however, that thanks to the fact that the W14 fixing system is able to change the tightening torque of the screw securing the elastic catch, its able to have a influence of the clamping force. Both fastening systems fulfill the minimum requirement for longitudinal resistance with an allowance and reach values much greater than 7 kN,
4. The suppression of impact loads is comparable, and torsional resistance is more favorable for the W14 system - 10% more than in the SB system.

Summing up, it can be concluded that lower vertical stiffness and greater longitudinal resistance indicate a certain advantage of the SB system. However, it should be noted that a similar suppression of impact loads of both systems and a sufficient longitudinal resistance of the W14 system allow to state that both systems tested in this respect are comparable.

Static and dynamic stiffness of the rail pads is a key parameter affecting the stiffness of the entire fastening node. In the case of the German railways DB AG, the static rigidity of the elastic rail pad is equal 50 kN / mm - 70 kN / mm, and dynamic rigidity from 50 kN / mm - 130 kN / mm at a frequency of 3 Hz - 5 Hz. The rigidity of the entire pavement structure is influenced by the resistance to rail rotation and the inverse value of the stiffness factor of the fastening, which is used in the calculations. [5] The value of the moment M resulting from vertical force Q and transverse Y is calculated from the formula according to [5]:

$$M = c_T \cdot \varnothing \frac{b^2 \cdot c_{stat}}{12} + \frac{c^2 \cdot c_{clip}}{2} \cdot \varnothing$$

index:

- $c_T$  the resistance value of the rail rotation in the fastening [kNcm/°],  
 $\varnothing$  angle of rotation of the rail in the fastening [°],  
 $c_{stat}$  static stiffness rail pads [kN/cm],  
 $c_{clip}$  stiffness of the elastic leg [kN/cm],  
 $b$  width of the rail pad [cm],  
 $c$  distance between the spring feet [cm].

The value of the transverse resistance of the fastening system being the consequence of the transverse force is calculated from the formula according to [5]:

$$H = c_H \cdot s_2$$

index:

- $c_H$  Inverse stiffness value [kN/mm]  
 $s_2$  Horizontal displacement of the rail foot with respect to the undercoat

The vertical reaction value is calculated from the formula according to [5]:

$$F_z = C_z \cdot z = (c_{stat} - 2 \cdot c_{clip}) \cdot z$$

index:

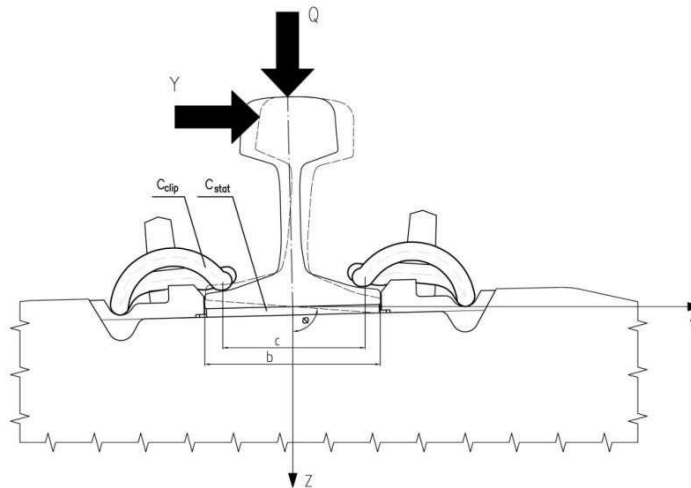
- $c_z$  vertical rigidity of the fastening system [kN/cm],  
 $z$  vertical elasticity [cm].

Fig. 8 shows the diagram of the forces acting on the fixing node.

The 13481-1 standard proposes dividing the shoulder pads into the following groups:

- soft spacers, stiffness <80kN / mm,
- spacers, medium stiffness 80 - 150 kN / mm,
- hard spacers, rigidity  $\geq$  150 kN / mm.





8. Diagram of transverse and vertical forces impacting on a fixing node  
Source: [5]

In tab. 2 presents parameters of static and dynamic stiffness depending on the temperature of applied rail pads in the DB Netz network.

Tab. 2 Static and dynamic stiffness parameters depending on the temperature of applied rail pads in DB Netz network [3]

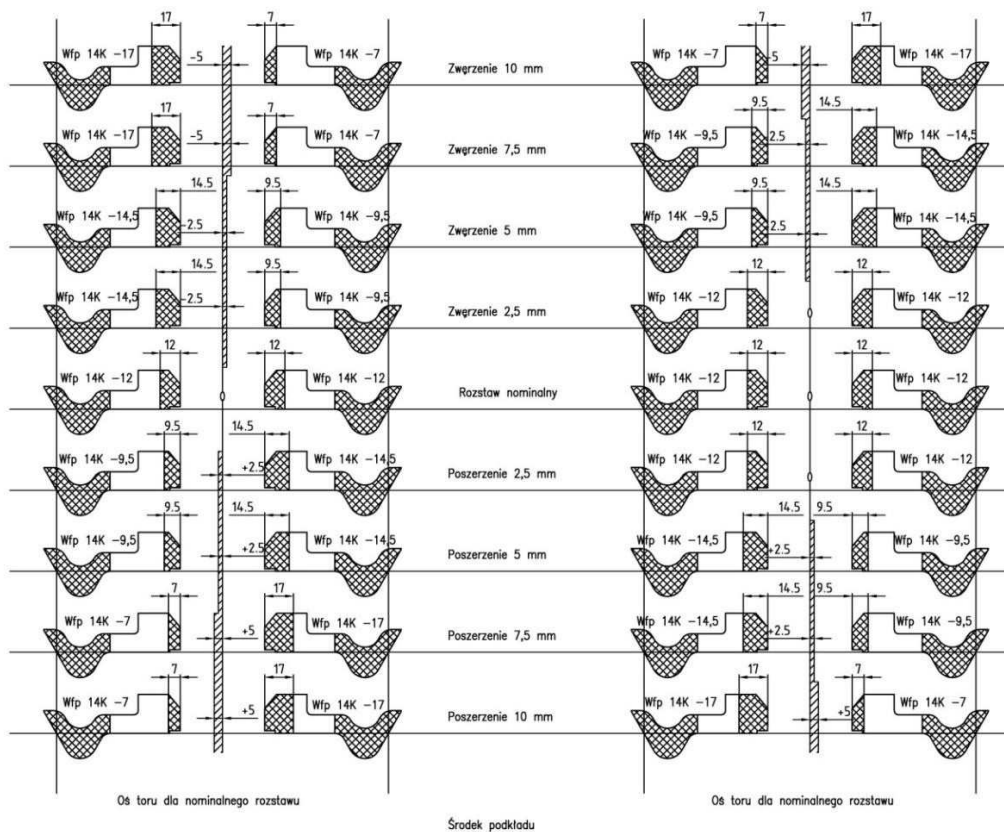
	cstat [kN/mm]		cdyn [kN/mm]		
	25 <sup>0</sup> C	-30-+70 <sup>0</sup> C	25 <sup>0</sup> C 5-30 Hz	-30-+70 <sup>0</sup> C 10 Hz	25 <sup>0</sup> C 100-2000 Hz
Zw700a	53	51-64	71-77	182-63	80-275
Zw900a	56	53-68	75-83	179-68	-
Zwp104NT	23	22-25	28-29	47-25	-
Zwp104NT	27	26-29	40-42	36-63	-
Zw1000NT	42	42-41	57-61	56-91	-

According to regulation [11], the nominal track width on the straight line measured between the inner edges of the track heads forming the track at a height of 14 mm below the upper running surface of the rails is 1435 mm. Due to the use of arches with radii below 250 m according to [11] it is necessary to design widenings of track gauge. Extensions are made to facilitate the entry of rail vehicles into the arch.

Extension of the track is performed by moving the inner rail towards the center of the curve. The transition from the nominal width to the increased should be made at the transition curve length. When using prestressed concrete sleepers it is necessary to use such solutions that adjustment is possible in the fastening system. To realize such an extension, in the SB system, the anchors of the fastening system should be changed in the foundation already at the stage of its production. For this, it would be necessary to make a set of additional forms and a supervised production process of dedicated foundations for a specific, individually designed arch. A much simpler solution is therefore the selection of movable elements included in the

fastening system. Unfortunately in the SB fastening system it is possible to a limited extent. According to [13] in order to adjust the track width, WKW 60-G insulating inserts are used. These inserts are larger than the traditionally used WKW 60 elements by 2 mm, so in the SB fastening system, it is possible to widen / narrow the track by a maximum of 4 mm in 2 mm increments. In connection with the above, it is not possible to use prestressed concrete sleepers with SB fastening on arcs with a radius less than 250 m. In the case of the W14 type fastening system, the adjustment is made using Wfp angles with different dimensions. During we use the angle plates, we can change the width of the track by narrowing and widening to 10 mm.

In the case of a track on which deviations of the permissible width have been found, it is necessary to determine the cause of the problem before proceeding to its adjustment. If the reason for the deviation is not the usage level of rails, run-off of the rail steel or permanent deformation of the rails, it is necessary to change the width in the fastening system. In the case of wooden foundations it is possible to change the position of the ribbed plate. If we take into consideration prestressed concrete sleepers with SB fastening, such measures, as already mentioned, are very limited, and in the case of W14 fastening, the extension is easily realized by replacing the angle spacers as shown in Fig. 9.



9. Angle plates for the W 14 fastening system with the possibility of adjustment  
 Source: own archive

In order to obtain the same neutral temperature in both rail tracks in the non-contact tracks a longitudinal forces adjustment is performed. The adjustment of longitudinal forces is carried out by one of the following three methods: free alignment (while conducting works in the temperature range of neutral), thermal (using heating devices whose task is to heat the rails to the desired temperature), tension (using rail stresses). [4] Regardless of the technology used during the procedure of adjusting the fixing of the rails, it is necessary to detach the feet of the elastic fastening systems. While in the case of the W14 fastening system, it is enough to

unscrew the bolt fixing the elastic catch and set it in the assembly position, in the case of securing the SB type it is necessary to dismantle the entire system. It should be noted that, in the case of elastic type SB, maximum 3 - 5 (depending on the type of the foot) can be removed and re-fastened. Higher number of cycles may cause its partial deformation, which will cause difficulty in the next clasp of the clamp in the anchor. Such an unfavorable effect does not exist in case of fixing W14, where it is possible to unscrew and tighten the bolt repeatedly.

The fastening system in the usage of current regulations [10] is considered as one of the interoperability constituents. It must meet the requirements for track resistance for applied load, minimum longitudinal resistance, and should not show changes after cyclic loads. The fastening systems analyzed in this work in terms of strength parameters and other features meet the normative requirements for the interoperability constituent. For the purpose of placing on the market, full testing and issuing of the EC declaration of conformity is necessary. The entity responsible for this may be: producer, distributor, and complete.

In the case of some system configurations, the producers of one system are many, since the components often come from various sources. The inability to perform pre-assembly results in the elements of the attachment system being sent separately to the recipient. We do not experience such difficulties in the case of the system, fixing W14, because the entire mounting is mounted in the production plant, pre-tensioned sleepers and complete with the foundation delivered to the construction site. On this basis, it is easy to identify components without the risk of assembly of components that were purchased by the track work contractor from unqualified sources.

The paper presents a comparison of two fastening systems: SB and W14 types. It can be generally stated that both systems are comparable. However:

- in favor of the SB system with the PKW PUR type rail underlayment, high prevalence in Poland,
  - lower vertical stiffness of the SB type fastening system, and greater longitudinal resistance, and thus the distribution of the load on a larger number of sleepers and the lower loading of the railway ballast is caused by the use of a rail pad with significantly lower stiffness. In relation with
- with the above, a rail pad should be selected in order to meet the requirements set by the Infrastructure Manager in the scope of rail deflection and foundation in the railway track,
- in favor of the W14 system, it is easy to change the track width, repeatedly fix and loosen the rails, and above all, the possibility of assembling all its elements in the transport position and delivering completely built-up sleepers for the construction.

The significant difference in vertical stiffness is related to the different stiffness of the PKW and Zw rail pads, used classically in PKP PLK and DB. On foreign railways, higher stiffnesses of over 300 kN / mm (DB) are usually used. Soft spacers - 100 kN / mm are used on lines with higher speeds because they are characterized by better suppression of higher frequencies. Compared with the PKW national dividers, however, they are much harder. It is considered essential that the manager of the national railway infrastructure - PKP PLK - define the range of stiffness of the fastening system depending on the purpose of the line.

### Source materials

- [1] Badania węzłów przytwierdzenia typu SB-TT-K3 oraz SB-TT-K4 do podkładu strunobetonowego zgodnie z normami serii PN-EN 13146:2012 oraz PN-EN 13481:2012. Sprawozdanie z badań Instytutu Materiałów i Konstrukcji Budowlanych Politechniki Krakowskiej, Kraków, grudzień 2015.
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