Apart from testing a complete fastening system, the procedure also involves the individual testing of spring clips, as one of the essential elements of the fastening system. The main reference documents in spring clip testing are "Krajowa Ocena Techniczna" (KOT) [2] and WTWiO ILK3D-5183-5/2007E.P. [21]. According to the above guidelines, spring clip testing is based on the assessment of:

- The condition of the surface and appearance according to KOT or WTWiO [2, 21] (often including magnetic particle tests according to requirements) under PN-EN ISO 9934-1:2017-02, PN-EN 10228-1:2016-07 [5, 15].
- The shape, dimensions, and construction tolerances according to KOT or WTWiO [2, 21].
- Hardness according to requirements under PN-EN ISO 6508-1:2016-10 [13] according to KOT or WTWiO [2, 21].
- Resilience according to requirements under PN-K-88171:1981 [14] and KOT or WTWiO [2, 21].
- Assembly strength according to KOT or WTWiO [2, 21].
- Microstructure according to requirements under PN-H-04505:1966 [17].
- Decarburization according to requirements under PN-EN ISO 3887:2018-03 [13].
- Fatigue strength according to KOT or WTWiO [2, 21].
- Anti-corrosion treatment according to KOT or WTWiO [2, 21].
- Marking according to KOT or WTWiO [2, 21].

The assembly strength assessment referred to in point 5 is applied only to SB spring clips. According to the reference documents [2, 21], the test involves assembling and disassembling a spring clip in a 1:1 real fastening joint model five times. The main criterion of approval is for dimensions "b" and "f" [Fig. 1] to remain within the limits of permitted deviations with at least 8 kN of load applied onto the insert. The reference documents have not defined the requirement concerning the measurements of the initial dimensions of "b" and "f" before the start of the assembly strength test. The reference documents [2, 21], according to point 2 above, mention the need to check the shape, dimensions, and construction tolerances on a defined number of samples collected from a given batch, but these samples are not subject to further tests which may deform them. The assembly strength test referred to in point 5 above is not performed on the same samples as those used in the test referred to in point 2 above.

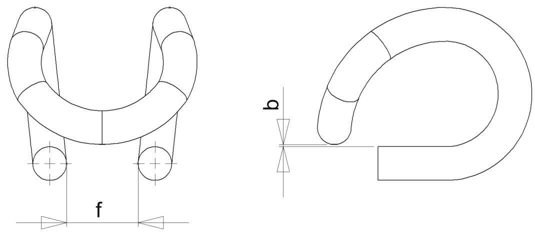

Fig. 1. Dimensions "b" and "f" of an SB4-type spring clip, measured during assembly strength tests [authors' own work based on [2, 21]

3. Test description

The assembly strength tests were performed on eight SB4-type spring clips made of steel 48Si7, taken at random from one product batch. The chemical composition of the steel - based on the certificates provided by the manufacturer – is presented in Table 1. The entire batch was tested following points 1÷10 listed above, and considered compliant with the approval criteria referred to in a reference document [2].

The test was carried out with the use of a pretensioned sleeper with anchors for spring fastening, a 0.6 m rail section, and other fastening components – a rail pad and an electrical insulating tie-down insert. The SB4 spring clip assembly strength testing station is shown in Fig. 2.

Table 1

Chemical composition of steel featured in SB4 spring clips (according to the metallurgical certificate – manufacturer's documentation)

Chemical composition [%]											
C	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Cu**	**Al**	**Ti**	**Mo**	**V**
0.4754	1.6738	0.6114	0.0136	0.0105	0.0336	0.0171	0.0130	0.0024	0.0014	0.0041	0.0014
W	**Sn**	**B**	**N**	**Nb**	**As**	**Sb**	**Pb**	**Co**	**Ca**	**Ta**	**H [ppm]**
0.0000	0.0012	0.0002	0.0050	0.0000	0.0044	0.0000	0.0010	0.0028	0.0000	0.0000	1.4000

[Authors' own work].

Fig. 2. SB4-type spring clip assembly strength testing station [authors' own work]

First, before the assembly, dimensions "b" and "f" of 8 selected sample items were measured in accordance with Fig. 1. Next, dimensions "b" and "f" were measured again after each operation of assembly and disassembly up to the fifth clip assembly and disassembly inclusive. Samples which did not comply with the dimensions given in the reference document [2] were intentionally not rejected. From among the eight tested clips, six were qualified to the next testing stage. They were assembled and disassembled five more times. After the final disassembly, dimensions "b" and "f" were measured again, and the operation of assembly and disassembly was repeated five more times, followed by taking measurements once again afterwards. The six selected sample items also had the clip's clamping force tested after being assembled and disassembled five, ten, and fifteen times. The test was performed with the use of a Sinus 250 strength testing machine (Fig. 3), which had clamping force testing equipment fitted on it (Fig. 4).

4. Test results and discussion

The obtained results of measurements of geometrical dimensions "b" and "f" are in line with the authors' expectations. They are presented in Table 2, and the clamping force test results are given in Table 3. The chart featured in Figure 5 shows the increase in the values of dimension "b" with each subsequent assembly and disassembly of the spring clip. An interesting aspect is that the increase is the greatest after the first fastening of the clip, and the lower the initial value of dimension "b", the greater the increase. After five operations of assembly and disassembly of the clip, the increase in dimension "b" becomes stable, which is seen best in the case of clips with dimension "b" in line with the guidelines ("b" = 0.8 mm and "b" = 1.3 mm). In the case of the spring clip with its dimension "b" 1.2 m below the required minimum value (–0.7 mm), a greater trend of increase was noticed.

Fig. 3. Sinus 250 strength testing machine with SB4-type spring clip clamping force testing equipment [authors' own work]

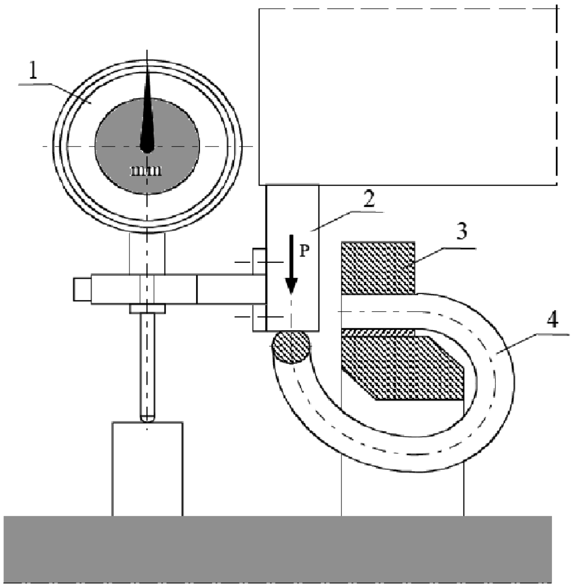

Fig. 4. Diagram of clamping force testing equipment: 1) displacement sensor to measure the changes in the values of dimension "b", 2) strength testing machine's element exerting displacement with clamping force "P", 3) spring clip fastening, 4) tested SB4 spring clip; authors' own work based on [2, 21]

Table 2

Results of measurements of geometrical dimensions “b” and “f” of eight SB4 spring clips

No. sample	Nominal dimension [mm]	Measurement results depending on the number of disassemblies n [mm]							
		Before the test	*n* = 1	*n* = 2	*n* = 3	*n* = 4	*n* = 5	*n* = 10	*n* = 15
B1	b =1$^{\pm 0.5}$	0.8	1.1	1.2	1.3	1.3	1.4	1.6	1.7
	f = 34$^{\pm 1}$	33.2	33.6	33.7	33.8	33.8	33.9	34.0	34.1
B2	b = 1$^{\pm 0.5}$	1.3	1.6	1.9	2.0	2.0	2.0	2.1	2.3
	f = 34$^{\pm 1}$	33.1	33.7	33.8	33.8	33.9	33.9	34.0	34.2
B3	b = 1$^{\pm 0.5}$	1.4	1.8	1.8	1.8	1.9	1.9	–	–
	f = 34$^{\pm 1}$	33.5	33.7	33.7	33.8	33.8	33.8	–	–
B4	b = 1$^{\pm 0.5}$	1.2	1.5	1.5	1.6	1.7	1.7	–	–
	f = 34$^{\pm 1}$	33.6	34.1	34.1	34.2	34.3	34.3	–	–
B5	b = 1$^{\pm 0.5}$	−0.7	φ0.2	0.0	0.1	0.1	0.1	0.2	0.4
	f = 34$^{\pm 1}$	33.6	34.2	34.3	34.4	34.4	34.5	34.5	34.6
B6	b = 1$^{\pm 0.5}$	1.3	1.7	1.7	1.8	1.8	1.8	2.1	2.1
	f = 34$^{\pm 1}$	33.4	33.9	34.0	34.0	34.1	34.1	34.2	34.3
B7	b = 1$^{\pm 0.5}$	1.0	1.3	1.3	1.3	1.4	1.4	1.7	1.9
	f = 34$^{\pm 1}$	34.2	34.3	34.4	34.4	34.4	34.4	34.5	34.6
B8	b = 1$^{\pm 0.5}$	−0.9	−0.2	−0.1	0.2	0.3	0.3	0.4	0.6
	f = 34$^{\pm 1}$	33.0	34.0	34.0	34.2	34.3	34.3	34.4	34.5

[Authors’ own work].

Table 3

Results of tests of clamping force after five, ten, and fifteen assemblies and disassemblies of SB4 spring clips

No. sample	Pressing force of spring clips [kN]		
	n = 5	*n* = 10	*n* = 15
B1	9.9	10.1	10.2
B2	10	10	10
B3	9.9	–	–
B4	9.9	–	–
B5	10	10.2	10.2
B6	9.8	9.9	10
B7	10	10.1	10.2
B8	10.2	10.3	10.3

[Authors’ own work].

The value of dimension “b” before and after clamping force tests remained constant, which proves that a clamping force test alone does not result in plastic deformation.

Table 4 includes a list of results of measurements for six samples whose dimensions were in line with the dimensional requirements under the guidelines [2, 21] before the assembly strength tests. It is important to stress that the guidelines [2, 21] do not include a requirement to measure the tested sample before the test in question. They only mention a requirement to check the values of dimensions “b” and “f” after the test. The change in dimension “f” after five, ten, and fifteen assemblies and disassemblies of the clip is within the defined tolerance limits. In the case of dimension “b”, in turn, we can see that the samples whose initial dimension “b” ≥ 1.2 mm did not comply with the dimensional requirements defined in the guidelines after the assembly strength test. The average increase in dimension “b” after the assembly strength test amounts to approximately 0.53 mm, which exceeds the tolerance limits for this dimension. This observation calls for a need to review the dimensional tolerance ranges related to the increase in dimension “b”.

The method of spring clip fastening in the joint suggests that dimension “b” is one of the dimensions determining the clamping force exerted by the rail onto the sleeper. It is a very important matter, translating directly into issues related to the safety of railway infrastructure use.

Measuring the clamping force after an assembly strength test does not, however, fully reflect the impact of the increase in dimension “b” on the actual clamping force exerted by the rail onto the sleeper. Some provisions of the WTWiO guidelines [21] use the term “testing the clamping force exerted by the spring on the insert”, which implies that the test should make it possible to obtain information precisely on the clamping force exerted by the rail on the sleeper. Unfortunately, this is not the case. The increase in dimension “b” should

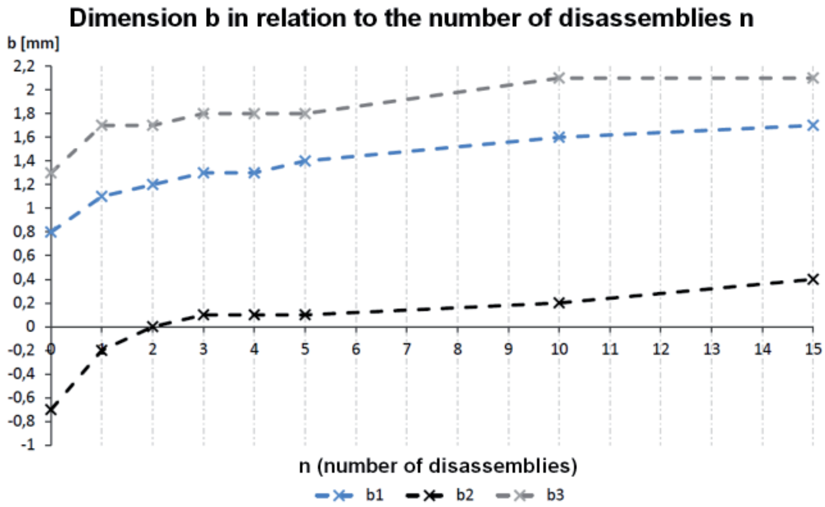

Fig. 5. The impact of the number of fastening operations n in the assembly and disassembly of an SB4 spring clip on the value of dimension "b" (b1 corresponds to sample B1, b2 – to sample B5, and b3 – to sample B6) [authors' own work]

Table 4

The impact of the assembly strength test on changes in dimension "b"

Measurement stage	Measurement results for individual samples compliant with the initial dimensional requirements [mm]					
	B1	B2	B3	B4	B6	B7
Dimension "b" before the test	0.8	1.3	1.4	1.2	1.3	1.0
Dimension "b" after the test	1.4	2.0	1.9	1.7	1.8	1.4
Increase in Δ "b"	0.6	0.7	0.5	0.5	0.5	0.4

[Authors' own work].

in reality reduce the pressure (clamping force) exerted by the rail on the sleeper. The tests carried out within the framework of this paper prove that the clamping force grows with the increase in the number of clip fastening operations, which leads to an absurd conclusion that the increase in dimension "b" translates into an increase in the clip's clamping force. To interpret these results, it is necessary to address the testing methodology imposed by the guidelines.

An outline of the clamping force testing equipment is provided in Figure 4. After the spring clip is fixed in the strength testing machine, it needs to be subjected to loading until a deflection of 11 mm is reached. The load needs to be kept at this level for 10 seconds, then reduced to reach a deflection of 8 mm, and then we should read the force value indication. The value of the clip's clamping force should be not lower than 8 kN.

If the clamping force test is performed in such a manner, according to the guidelines [2, 21], the initial value of dimension "b" appears to be irrelevant. What matters here is deflection, meaning the value of increase, and the test itself represents the tested material's response to the deformation it is subjected to, which may, of course, partially simulate the clip's on-track behaviour during train passage. An increase in the clamping force observed in tests may also be a sign of changes occurring in the clip's steel as a result of deformation (e.g. material consolidation) or the impact of other geometrical aspects related to the spring's structure (curves and bend radii) on the clip's behaviour during such tests.

The question of how dimension "b" of a spring clip affects the clamping force remains unanswered if we apply the methodology imposed by the quoted guidelines [2, 21], and logic-based expectations and assumptions are not materialised in the obtained test results. To analyse the actual impact of changes in dimension "b" of a spring clip on the clamping force exerted by a rail on the underlying structure, we need to make use of some other testing method, which should be first borrowed from a methodology applied in testing entire fastening systems.

5. Conclusions

Contemporary fastening systems are required to offer effective vibration damping [3, 4] and to comply with requirements under the relevant applicable legal acts, standards, and international regulations [19, 20] at the same time, especially when it comes to the clamping force (pressure) exerted by rails on the underlying structure.

Unfortunately, it is impossible to determine this force correctly when following the methodology applied in tests designed for spring clips based on the existing applicable reference documents [2, 21]. To this end, it is necessary to apply a methodology in line with PN-EN 13146-7:2019-05 [10].

Moreover, the results of the tests carried out for the purpose of this paper show that, during a strength assembly force, the value of dimension "b", which directly determines the clip's pressure exerted on the insert and indirectly determines the rail's clamping force exerted on the underlying structure, grows so much (on average) that it exceeds the tolerance range adopted for this dimension. This has not been considered in the guidelines [2, 21] related to the dimensional requirements for assembly strength tests.

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