CETRA2020
20 - 22 May 2020, Pula, Croatia
6th International Conference on Road and Rail Infrastructure

Development of the new “DIV” rail fastening system

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Abstract

The primary role of the rail fastening system is to position and fasten the rails to sleepers and transfer the vehicle load from the rails to the track substructure. The type and characteristics of the fastening system are usually chosen depending on the required elasticity of the track, the design load, and the type of rail. The rail fastening system has also a significant effect on the emission of noise and vibration that occurs during the operation of rail vehicles, so the right choice of fastening system contributes to noise and vibration mitigation. Worldwide, there are many types of rail fastening systems, which differ in design, construction and technical characteristics. The most used rail fastening systems are W-clip, E-clip, Nabla clip, etc. Various types of fastenings are a result of effort of both independent institutions, rail equipment manufacturers and a significant number of research centres of the developed railway authorities. When optimizing the railway track, it is necessary to choose the right properties of the fastening system, which will ensure safe and reliable operation of railway vehicles with a minimum of noise and vibration emission. The characteristics of the fastening clip and the rail pad have the greatest influence on the mechanical behaviour of the fastening system. The Faculty of Civil Engineering of the University of Zagreb cooperates with DIV d.o.o., a manufacturer of railway equipment, on an R&D project “Development of the elastic fastening system DIV”. With the aim of developing a new fastening system, this paper primarily analyses the properties of existing fastening systems. A meaningful evaluation of the rail fastening systems requires the understanding of the geometry, materials, mechanical properties and the utilisation of the clip and the rail pad. The new fastening system should meet the requirements defined in the standards EN 13146 and EN 13481.

Keywords: railway track, rail fastening system, rail clip, rail pad

1 Introduction

The dynamic forces acting on the structure have increased significantly due to the increase in rail vehicle speeds and the development of high-speed railways in recent decades [3]. Subsidence of individual layers and degradation of the track structure are challenges that occur on modern railway tracks. To reduce the dynamic forces and improve the track quality, an elastic fastening system is usually installed to connect the rails and sleepers. The main functions of the fastening systems are: transfer forces from the rails to the sleeper, ensuring a constant clamping force over time, invariable elastic behaviour over time and a durability of all elements, low cost and ease of installation and maintenance. Moreover, fastening system should provide: passenger comfort, damping of vibrations and shock loads caused by rail traffic, maintenance of track gauge within certain tolerances, provision of electrical insulation between rails and sleepers, torsional resistance to rail rollover, restraint against longitudinal rail displacements [4]. In the case of increased stresses in the rail due to dynamic effects caused by the railway vehicle passing over the rail, the elastic force of the fastening clip on the rail plays a vital role. It provides elastic support of the rail during vertical movement, absorbs vibrations and achieves high resistance to longitudinal movement and lateral rotation of the rail. Furthermore, it ensures constant contact between the rail and the sleeper and must be sufficient for all load cases, including wear of individual components [3]. Depending on the fastening system and customer requirements, the clamping force varies in the range of 7.5 to 12.5 kN and deflections of the clip toe between 10 and 15 mm. The clip needs to have a large deflection during the installation phase so that the clamping force is not significantly affected by variations in the thickness of the pads, insulators and rail. The rail clamping force requirement is determined by the rail size, vehicle weight and speed, the nature of the track, curve radii, temperature range and so on. According to European standards, the minimum resistance force against longitudinal movement of the rail by the fastening system is 7 kN for most mainline tracks and 9 kN for high-speed rail and heavy freight lines. This results in a nominal clamping force per clip of a minimum of 8.5 kN for mixed traffic line and 10 kN for the more severe applications [5].The main components of the elastic fastening system are therefore an elastic rail clip and an elastic rail pad.

The elastic rail clips used in the railways of the world are usually divided into two categories: the first uses a threaded nut/screw with a bolt to apply a force to the clip steel (W-14, Nabla), and the second category are the self-tensioning clip (E-2000) [6].

An elastomeric rail pad is an element of track fastening accessories that is placed under the rail at the fastening point. Its surface may be flat, plugged, or grooved. A rail pad installed between the rail and the sleeper prevents wear of the sleeper top and protects it from the effects of loading. Its effect is also manifested through the reduction of high-frequency vibrations caused by the passage of rail vehicles. The thickness of the rail pads varies from 4.5 mm to 15.0 mm. For use on 60E1 rail fastening systems, 180 mm long and 148 mm wide rail pads are used [7]. Materials from which the rail pad is most commonly made are ethylene vinyl acetate (EVA), high-density polyethylene (HDPE), thermoplastic polyurethane (TPU), High Sylodyn (HS), natural rubber (NR), etc. The materials used to make the rail pads are characterized by very high elasticity, low temperature-dependent stiffness, low dynamic stiffness, good noise damping of the track, good aging and weathering resistance, low water absorption and very good resistance to UV radiation and ozone. Some of the rail pads used with their associated stiffnesses are: Zw700a (53 MN/m), Zw900a (56 MN/m), Zw 661-6 (347 MN/m), Zw 687 (315 MN/m), Zw700 (68 MN/m) [8]. The stiffness of the 4.5 mm thick rail pad of the Nabla fastening system is 1300 MN/m, while the 9 mm thick rail pad has a stiffness of 200 MN/m [9]. The stiffness of a fastening system is critical to the long-term performance of the fastening system under repeated axle loading. Stiffness is closely related to the degree of wear to which the fastening system components are subjected, and the resulting life of the system. More elastic fastening systems tend to accelerate component wear, while stiffer fastening systems may cause problems such as rail breakage, pumping sleepers, or ballast crushing [10]. By reducing the stiffness of the fastening system, the vehicle load is transferred to a larger number of sleepers. This reduces the load on the individual sleeper and the rate of load growth and prolongs the life of both the sleeper and rails. Reducing the stiffness also lowers the rail frequency, which has a positive effect on the overall design of the track and reduces traffic noise and vibration [11].

The project development of the elastic fastening system “DIV” consists of 2 phases: industrial development of the clip and experimental development. The industrial development is divided into the following steps: development of clip models (development of 9 models and selection of the top 3), development of tools for the production of the elements of the “DIV” fastening system, internal testing of experimental series, laboratory tests, development of procedures and machines for the assembly and disassembly of the “DIV” clip, development of a trial section length (main project of the test section length 200 m - 100 m reference section with the fastening system W-14, and 100 m section with the “DIV” fastening system), and intellectual property protection. Steps of experimental development are: construction of a test section and installation of measuring equipment, testing of “DIV” elastic clip on test section and preparation for commercialization.

2 Characteristics of the W-14 and Nabla fastening systems

The most important properties of the fastening system in the process of the development of a new type are defined in [1], [2]. These standards for fastening systems for concrete sleepers consist of the following parts: determination of rail longitudinal restraint, determination of torsional resistance, determination of attenuation of impact loads, effect of repeated loading, determination of electrical resistance, effect of severe environmental conditions, determination of clamping force and uplift stiffness, in-service testing, determination of stiffness, and proof load test for pull-out resistance. W-14 and Nabla clip’s great advantage is the possibility of adjusting the clamping force on the rail-foot by tightening the nut/screw. The characteristics of the W-14 and Nabla fastening systems will be presented. Better understanding of current system characteristics leads to optimization of the new “DIV” fastening system .

2.1 W-14 fastening system

According to the technical specifications of the W-14 fastening system, the rail is fastened with an approximately 12 mm deformed W-14 clip and tightened with a fastening force of 2x9 kN. The central bending of the clip, where it makes a second stop (after the clip has deformed by about 14 mm), protects the rail from lateral rotation [12]. Structural Testing Laboratory of the Faculty of Civil Engineering of the University of Zagreb performed laboratory testing of W-14 fastening system [14]. The tests of the rail fastening system for one-piece prestressed concrete sleepers were carried out according to the requirements given in standards [1], [2]. The specified fastening system belongs to category C with a maximum design axle load of 260 kN and a minimum track curve radius of 150 m. Comparative analysis of fastening system W-14 characteristics from literature [13] and from own laboratory testing has been performed, Table 1.

Table 1. Tested parameters of the fastening system [13], [14]

Parameters	Fastening system	
	W-14 (Poland) [14]	W-14 (Zagreb) [15]
Dynamic vertical stiffness	100,4 MN/m	109,4 MN/m
Static vertical stiffness (before cyclic loading)	86,6 MN/m	89,5 MN/m
Static stiffness (after cyclic loading)	104,6 MN/m (switch <25%)	110,3 MN/m (switch <25%)
Longitudinal resistance (before cyclic loading)	14,0 kN	12,47 kN
Longitudinal resistance (after cyclic loading)	13,2 kN (switch <20%)	11,29 kN
Clamping force (before cyclic loading)	19,7 kN	16,96 kN
Clamping force (after cyclic loading)	18,6 kN (switch <20%)	14,92 kN (switch <20%)
Torsion resistance	1,27 kNm/1°	0,86 kNm/1°
Suppression of impact loads	47,30%	

2.2 Nabla fastening system

The elastic clip Nabla is a trapezoidal elastic plate with two axes of elasticity: one perpendicular to the rail and the other parallel to the rail, called the ridge. It achieves the clamping force by tightening the screw up to a certain degree of tightening. Between the plate and the rail foot, there is an elastic plate made of plastic. Advantages of Nabla are the very good elastic properties and the always constant clamping force. Disadvantages are the impossibility of using it with the B70 sleeper and the necessity of retightening the screw (regular retightening of the screw to ensure the clamping force). The load-deflection curves of the W-14 clip and the Nabla clip are shown in Figure 1. together with fastening clip without secondary stiffness [15].

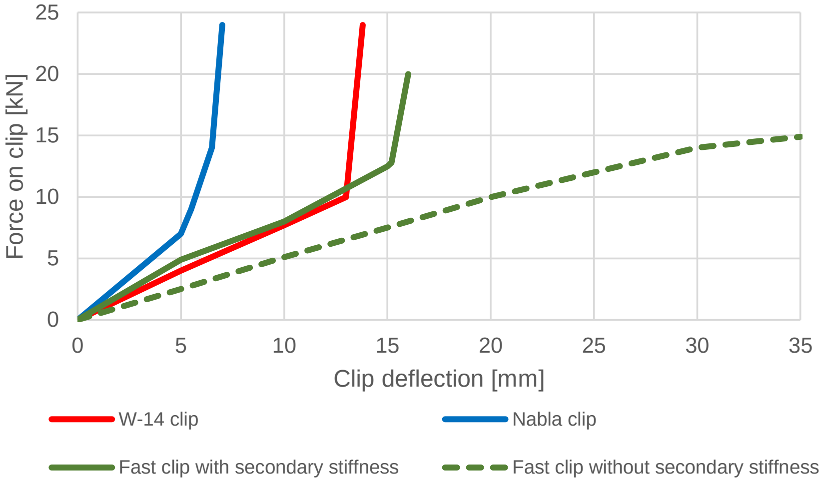


Figure 1. Force on clip and deflection diagram [15]

3 Research carried out on the development of the “DIV” fastening system

As part of the project to develop a new fastening system “DIV”, the following tests have been carried out so far for the W-14 and Nabla fastening systems: the steel tensile testing, 3D scanning of the existing fastening systems, static stiffness test of the elastic clips, static stiffness test of the rail pads. The conducted tests of the existing fastening systems, which are necessary for the development of a new system that is currently in the modelling phase are presented in chapter below. Detailed numerical models of the new “DIV” fastening system are created. A numerical model was developed for each variant, on which two types of simulations were performed. The first simulation is the assembly of the fastening system by pushing the clip from the unmounted to the mounted position, and for this analysis the diagrams "default forced displacement of the clip - the achieved tensile force in the screw" are required. A second simulation was performed to demonstrate the resistance of the clip to the lifting of the rail, simulating the passage of a railway vehicle along the rail. All numerical models include data on the material model of the clip obtained through testing, i.e. the same material model was used as in the variants of the previous phases. Yielding point of the clip should be precisely determined.

3.1 Tensile testing of the steel

The samples were taken and shaped in accordance with requirements of HRN EN ISO 6892-1: 2016 and tested at room temperature with no deviations from the standard. Three specimens of the hardox-400 without weld, three welded hardox-400 specimens and four specimens extracted from Nabla with additional welded hardox-400 were tested. The test was performed on a Z600 universal static testing machine. The force measuring device is class 1, according to the standard HRN EN ISO 7500-1. The strain measurement of the test samples in both the elastic and plastic range was conducted using an class 1 extensometer. The obtained average tensile strength of the samples without weld is 1124.23 MPa, of the welded samples is 1184.27 MPa, and of the Nabla samples is 1178.53 MPa.

3.2 3D scanning of the existing fastening systems

3D scanning was performed using an industrial high-resolution 3D scanner ATOS – GOM. The 3D scanning of the rail fastening elements resulted in files of type "STL". The STL file stores information about the geometry of the 3D model without colour and texture. In addition, STL files are suitable for later manipulation in a CAD tool and FEM software packages such as Abaqus software. Fastening systems over which 3D scanning has been performed are Nabla and W-14. The purpose of 3D scanning is to achieve high accuracy of numerical models of current fastening systems. Figure 2. shows laboratory setup for the purpose of the 3d scanning.

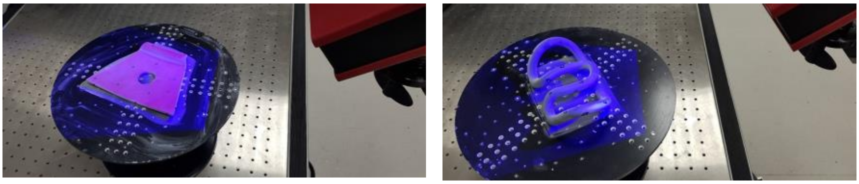


Figure 2. 3D scanning Nabla clip (left); 3D scanning of W-14 clip (right)

3.3 Static stiffness testing of elastic clips (Nabla and W-14)

The test was performed on a Z600 static testing machine of 600 kN in capacity. The test was performed using a displacement control with load retention every 500 N, as shown in Figure 3. The test load measurement was performed using a 50 kN load cell, and the 3D displacement and strain field measurement was performed using the “Aramis” stereophotogrammetry system. During the test, the displacement and strain field of the surfaces of the clips were measured in the increments of the application of vertical load of 500 N. The load was applied to the samples up to the moment when the contact of the clip with the adapter is established, i.e. until the "second contact", which is manifested during the measurement by a sudden increase in the amount of force without an increase in the deformation of the clip.

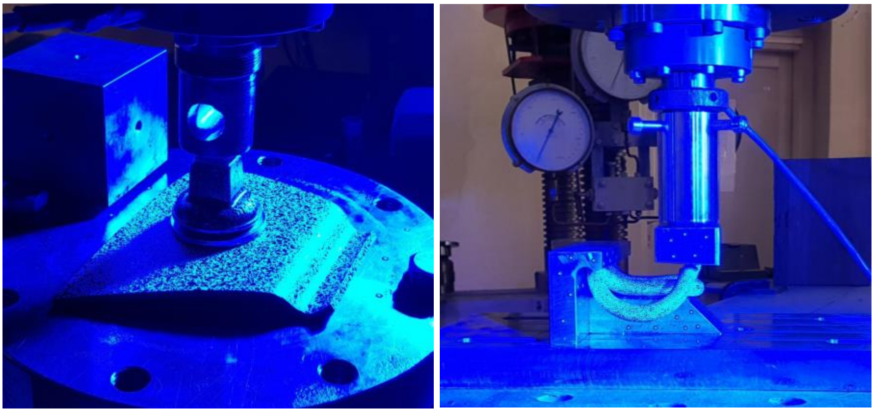


Figure 3. Laboratory testing of static clip stiffness: Nabla (left) and W-14 (right)

Diagrams of the vertical displacements of selected points of the clips as a function of the applied load are shown below in Figure 4. The same diagrams show the direction whose slope represents a certain static stiffness of the clips.

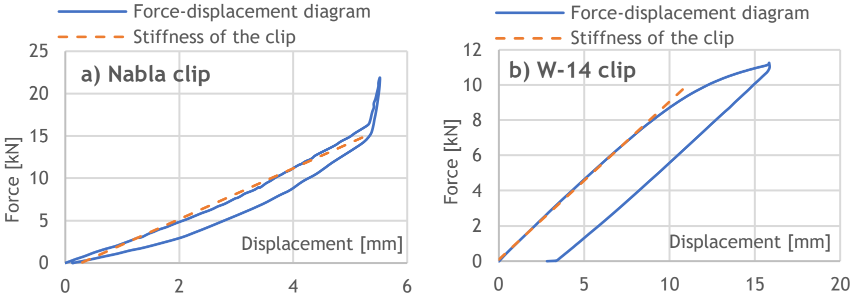


Figure 4. Vertical displacements depending on the applied load: Nabla (left) and W-14 (right)

From the linear part of the graphs shown in the previous figure, the stiffness of the clips (dashed line) is determined and amounts 3.00 kN/mm for Nabla clip and 0.90 kN/mm for W-14 clip.

Comparison between obtained static stiffness of the Nabla clip according to the model and according to Aramis system is shown in Figure 5.

In order to determine the stiffness of the Nabla clip, a simple numerical finite element model (FEM) was made, consisting of a Nabla clip, a screw made of steel and two plate components. One of the plate components is made of polymer material PA66, and the other, which represents the rail foot, is made of steel. The pressing element is accompanied by material obtained by testing on Nabla clip samples.

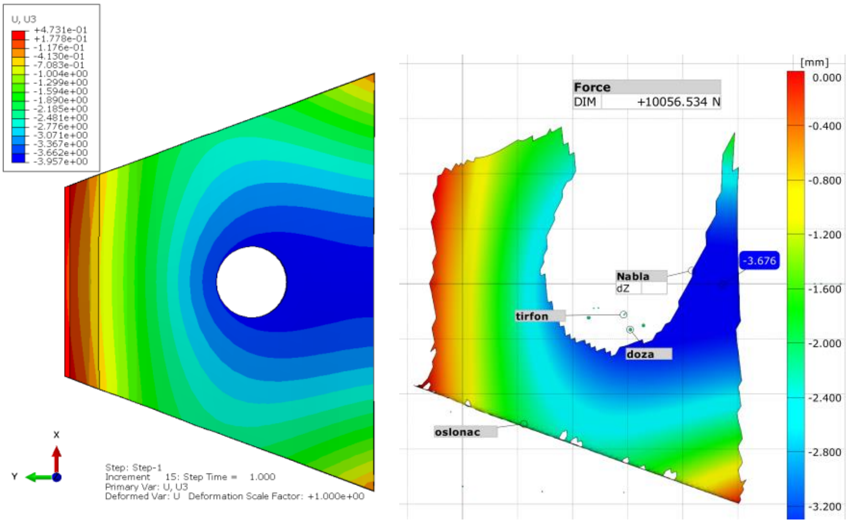


Figure 5. Results of the static Nabla clip stiffness test: according to the Abaqus model (left), and according to static test result analysed using Aramis system (right)

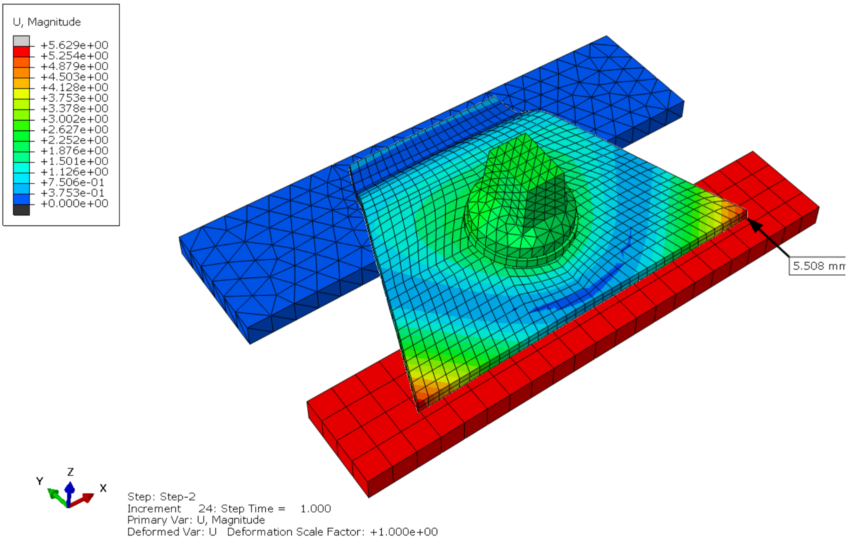


Figure 6. Strain plot of the Nabla surface due rail lifting

Figure 6. shows strain plot of the Nabla surface due rail lifting. To be able to determine the behaviour of the clip when the rail is lifted, a diagram of the relationship between the lifting force and the clip displacement (Figure 7.). On the same graph, changes in the slope of the curve and changes in the stiffness can be

observed. The first such change is identified as the "second point of contact ", which represents the moment when the curvature of the clip foot in the *xz* plane in contact with the rail foot is completely flat (full contact phase). The second change in the slope of the curve represents the moment when the screw begins to take over the bending moment caused by the lifting force.

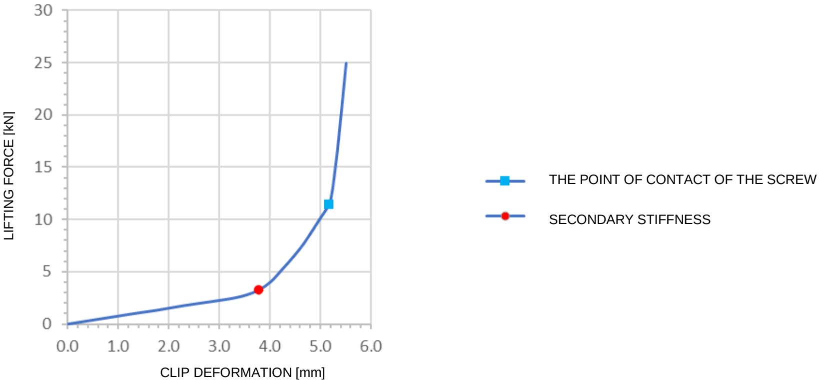
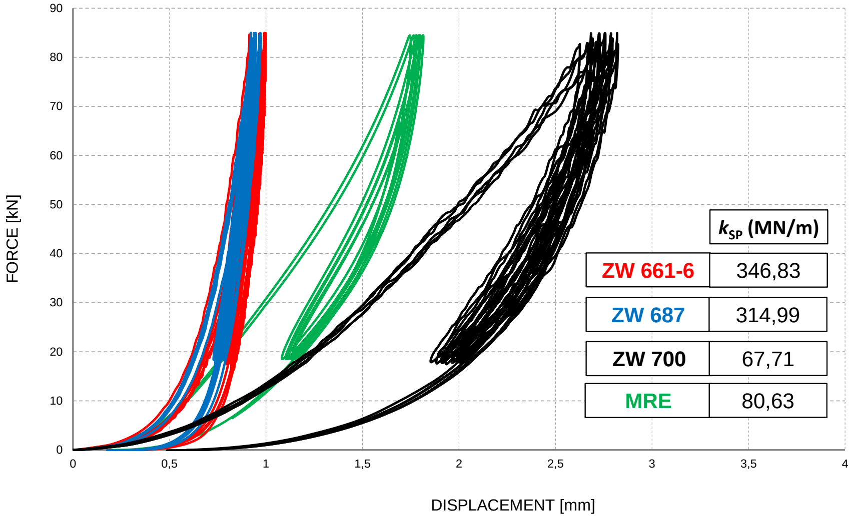


Figure 7. Nabla - Lifting force and clip deformation graph

3.4 Rail pad static stiffness testing

Static stiffness tests of rail pads were carried out at room temperature according [1]. Five samples of ZW 661-6, ZW 687, ZW 700 (used for the application of W-14 fastening system) and three MRE (used for the application of Nabla fastening system) rail pads were tested. Test conditions and load values were determined for the corresponding fastening category according to [2]. The static stiffness test of the rail pad was performed on a universal static testing machine with a load cell of 600 kN in capacity. The force measuring device is class 1. A rail pad is inserted between two 10 mm thick metal plates through which the load is distributed. The abrasive cloth was also inserted between the rail pad and the plates. The compressive load is applied to the pad using a rigid metal plate. The displacement of a rigid metal plate was measured with four inductive transducers (LVDT), 2xWA10 mm and 2xWA 50 mm. First, the maximum force F_{SPmax} is applied then the force is reduced to the value of F_{SP1}. Then two more cycles are repeated with the same load and unload at a loading rate of 120 kN / min. After that, the force is kept at the value of F_{SP1} for 30 seconds, and then the sample is loaded again with the force $F_{SP2} = 0.8*F_{SPmax}$. The static stiffness of the k_{SP} is determined based on the 4th cycle as secant stiffness at the values of the force F_{SP1} and F_{SP2} and the corresponding displacements.



	k_{SP} (MN/m)
ZW 661-6	346,83
ZW 687	314,99
ZW 700	67,71
MRE	80,63

Figure 8. Measured static stiffness of the rail pads

4 Conclusion and further discussion

According to [15], a modern railway track should have a low static stiffness coefficient $\rho_{static} < 100$ MN/m for the fastening, as derived from the Load-Deflection curve of the pad. It should also have a compatibility of the clip and the rail pad of the system as it is derived from the combination and comparison of the load-deflection curves of the clip and the rail pad (toe-load in each case >8 kN). The secondary stiffness of the clip should reduce the “rail tilt” and keep it below a maximum limit of approximately 2 mm. The development of a new fastening system is a very comprehensive process consisting of modelling, laboratory testing, field trials, marketing and adoption by track operators. Once optimal models have been determined and the selected model has been manufactured, it is necessary to conduct laboratory tests on the properties of the new fastening system. The laboratory measurements that provide the required mechanical properties of the new fastening system were firstly conducted on an existing (W-14 and Nabla) systems. Such an approach is crucial to establish a testing methodology that can be used to define the characteristics of the newly developed system. Further investigations for the development of a new fastening system are mainly to test the dynamic properties in the low and high-frequency spectrum of the elastic clip and the rail pad. It is also necessary to investigate the static and dynamic properties of the whole assembly. After performing the dynamic tests in the high-frequency spectrum, the vibroacoustic properties of the fastening system will be better known. Finally, after conducting static and dynamic laboratory tests on the assembly and each individual element (rail clip and rail pad), a 12-month monitoring period will be carried out in the field to evaluate the properties of the new “DIV” fastening system.

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