FE MODELLING AND GEOMETRIC PARAMETRISATION OF SKL-TYPE ELASTIC CLIPS

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Abstract

The primary function of rail fastening clips is to ensure sufficient clamping force by which the fastening system resists movements of the rail within its fixing place under all loading conditions. Since the clamping force at the rail foot is achieved by the deformation of the elastic clip, the stiffness of the clip and thus the magnitude of the clamping force depend on the material properties and geometry of the clip and are essential factors affecting the complex mechanical behaviour of the fastening system. In this paper, to conduct a parametric study of the clips, a visual script for SKL clip geometrical parametrisation has been developed using Grasshopper3D, an add-on for Rhino3D. The CAD model obtained in this way can be easily imported into Abaqus, where Finite Element Analysis (FEA) can be performed on the geometrically parametrised clip model, providing a good insight into the change of clip stiffness.

Keywords: rail clip, SKL 14 clip, rail fastening system, parametric analysis

1 Introduction

With the development of modern railways in recent decades, traffic speeds have increased, as have the axle loads acting on the track structure when a railway vehicle passes over the track. Because of the larger amplitudes and higher frequencies of dynamic forces, problems related to the rail fastening systems have been observed on some sections of railways around the world, especially damage and breakage of the elastic clips due to permanent deformation caused by its material fatigue (Figure 1a) [1-3]. A fastening system usually consists of several components, such as elastic clips, angle plates, screws, and a rail pad (Figure 1b), and its primary function is to elastically connect the rail to the sleeper.
Rail clips, installed in more than 90 % of railway networks worldwide, are wire-shaped clips made of spring steel bar and steel plate-shaped clips with stiffer mechanical properties compared to wire-shaped ones. SKL type clips belong to the group of wire-shaped clips. They are characterised by their simple installation and maintenance and high resistance to uplift and torsional rotation of the rail [4, 5]. There are several types of SKL clips that differ in dimensions and curvatures. Since the clamping force is achieved by the deformation of the clip during its installation, the shape and dimensions of the clip are essential parameters that affect the mechanical parameters of the clip, e.g., clip stiffness, and thus the static and dynamic parameters of the entire fastening system. The static behaviour and the static stiffness of a clip can be described by the toe load-displacement curve, which can be obtained by a quasi-static experimental test. The various types of SKL clips are shown in Figure 2a and their

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force-displacement curves in Figure 2b. A comparison of the curves shows that the shape of the clip has a crucial influence on the clip stiffness. For all the curves, the change in the curve inclination can be seen at the point called “second contact”, the moment when the centre loop of the clip touches the rail foot during the uplift of the rail. This is characteristic of all the SKL clips, so it is often said that they have a secondary stiffness by which these clips provide high resistance to uplift and torsional rotation of the rail.
The most commonly used SKL clips, installed on railway networks in more than fifty countries worldwide, are SKL14 clips of Vossloh’s W14 fastening system [6]. Although they have proven to be one of the most effective fastening systems, the breakage and damage of this type of clips have been detected on some track sections worldwide [7, 8]. Therefore, the mechanical properties and thus the efficiency of the W14 fastening system and SKL 14 clip should be improved.

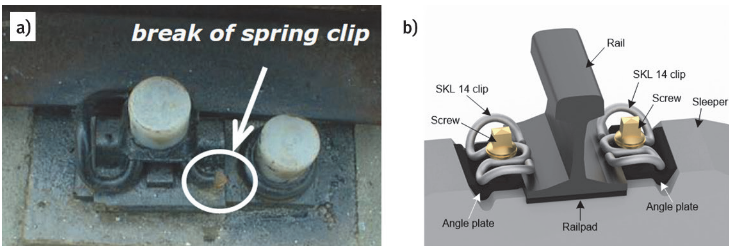

Figure 1 a) The breakage of an elastic clip caused by material fatigue [1]; b) A schematic view of W14 fastening system and its components

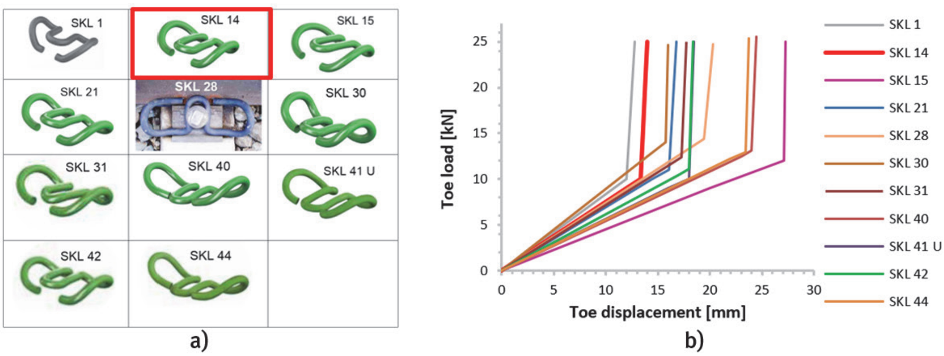

Figure 2 a) Various types of SKL clips; b) their toe force – toe displacement curves (data used for the curves: [1, 6, 9, 10, 11, 12])

In recent years, the development of computer technology allowed engineers to conduct computer experiments on a digital dual without needing a physical one [13]. Such an approach saves time and money, but it is only applicable when a digital prototype simulates the behaviour of an actual, physical prototype. Aware of the advantages of computer experiments, numerous research has been conducted during the last two decades to study the mechanical behaviour of clips and fastening systems which prove that mechanical behaviour improvement of the rail clips can be achieved by modifying their geometry. Therefore, in this paper, to study the influence of geometry change of the SKL 14 clip on its static behaviour, a visual script for geometric parametrisation of the clip has been developed in Grasshopper3D [14], an add-in for Rhino3D [15]. The numerical analyses of the modified clips has been conducted using simple FE models and CAE (Computer-Aided Engineering) tool, Abaqus [16].

2 FEA analysis of the clips

2.1 CAD model and geometrical parametrisation of the SKL 14 clip

The development of a FE model presented in this study can be presented with a few steps shown in Figure 3. FE model built with a good geometric accuracy allows the possibility to exclude geometry errors of the numerical model [17]. Due to the complex geometry of the clips and to avoid the geometry error, a 3D scan of the real clip is often performed before creating a spatial model in a CAD (Computer-Aided Design) tool. In this paper, the same has been conducted for the SKL 14 clip (Figure 3a). The 3D scan was imported into the CAD tool Rhino3D (Figure 3b), where the spatial CAD model was built using a visual script developed in Grasshopper3D (Figure 3c and Figure 4). Since the visual script requires only a clip axis curve, which can be reconstructed from the 3D scan, the visual script allows the geometric parametrisation of any SKL clips. The models obtained in this way can be easily imported and further processed in Abaqus (Figure 5d).
Two parameters were chosen to conduct parametric analysis of the clip: the diameter (Figure 5a) and the ScaleX parameter that scales both wings of the clip in the x-direction, as shown in Figure 5b. The parameters of the original and modified clips are shown in Figures 5a and 5b and are listed in Table 1.

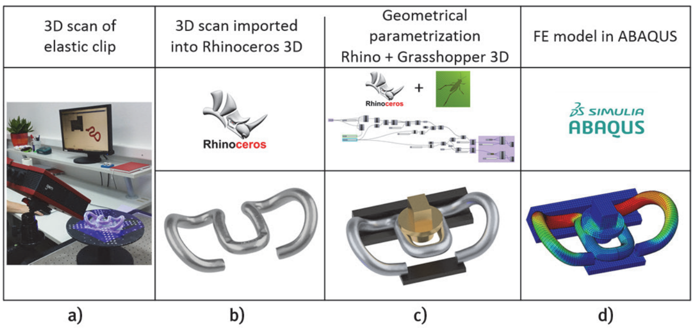

Figure 3 The steps of creating a FE model of the SKL clip

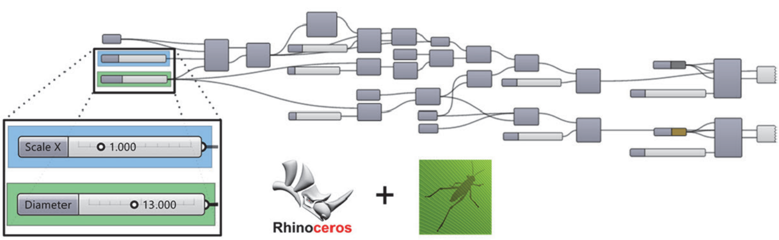

Figure 4 Grasshopper visual script for CAD model construction

Figure 5 a) Top view of the clips: change of ScaleX parameter (red – original, blue – ScaleX1.5 clip); b) Cross-section of the clip: change of clip diameter (red – original, green – D14 clip)

Table 1 Modified parameters of the clips

Clip/Parameter	D [mm]	ScaleX
SKL 14 (original)	13.0	1.0
D14	14.0	1.0
ScaleX1.5	13.0	1.5

2.2 Simulation of the quasi-static test and verification of the FE model

In addition to the SKL clip model, the presented visual script also creates CAD models of the other components of the FE model: a screw, a toe and a rear plate, which were imported and processed in Abaqus, forming together a digital dual (0a) to a physical prototype. In Abaqus, the spatial models of all the components were meshed with hexahedral finite elements. The type, size, and the number of finite elements and nodes of the final FE mesh are listed in Table 2. The fixed boundary condition was assigned to the top of the screw and bottom of the rear plate, as shown in 0a. Besides the clip's geometry, material properties are essential parameters in the numerical analysis of clips that significantly affect the clip's static behaviour. Due to often occurrence of plastic deformations in clips, it is also crucial that the material model of the clip FE model is defined as nonlinear or at least bilinear. In this study, the spring steel material model assigned to the FE model of SKL 14 clip was bilinear with elastic modulus E = 210000 MPa, yield stress σ_y = 1170 MPa and tensile strength σ_u = 1350 MPa. The steel material assigned to the other components was a linear model with E = 210000 MPa.
The static behaviour of the SKL 14 clip and its force-displacement curve was determined using FEA by simulating the experimental quasi-static test, i.e., by applying a toe displacement of 16.8 mm (0a). The spatial distribution of the stresses of the original clip (0b) showed the highest stresses in the rear part of the clip, and the maximum stress is 1180 MPa. Therefore, this part of the clip should be observed and analysed carefully because the maximum stresses location is where the first damage due to material fatigue can be expected. Since the use of spatial FE models showed an advantage in analysing the static behaviour of the SKL clips, they should be used in the fatigue analysis.

Table 2 Type, number, and size of finite elements and nodes of the FE models

FE model of the clip	Type of finite elements	Number of finite elements	Number of nodes	Size of finite elements
SKL 14	C3D8R	13970	17085	2.5
D14	C3D8R	13970	17085	2.5
ScaleX1.5	C3D8R	15222	18648	2.5

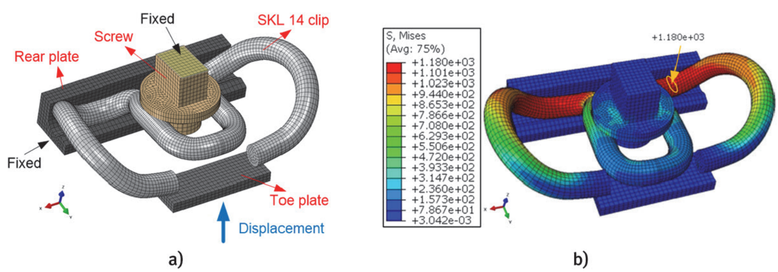

Figure 6 a) the components of the full SKL 14 FE model and assigned boundary conditions; b) distribution of spatial stresses obtained with FEA and location of maximum stress

To confirm the accuracy of the FE model, the FEA results were validated with experimental data obtained by using the digital image correlation (DIC) system Aramis for real-time 3D measurements displacements and surface strain [18]. The test assembly and the displacements of the clip, obtained by applying the toe load, are shown in Figure 7a. For this loading case, the force-displacement curve for the P01 point is constructed and shown in Figure 7b, where it can be seen that the clamping force is achieved at the toe displacement of approximately 11 mm.
Finally, the force-displacement curve obtained by FEA is compared with the curve obtained by the experimental quasi-static test of the clip, as shown in Figure 8. Since the experimental test is performed for only one clip sample, the numerical results are also checked with the experimental data from [7]. The comparison of the curves showed high accuracy of the FEA results, and this proved that the FE models are suitable for static behaviour assessment of the SKL 14 clip and SKL clips in general.

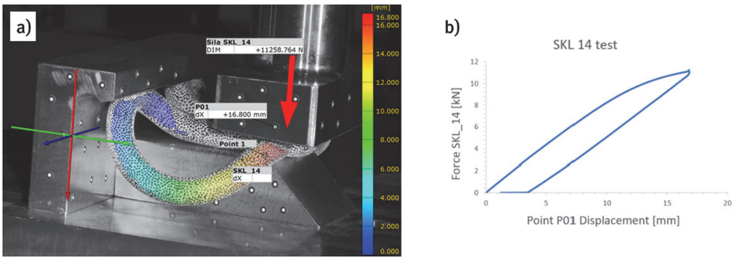

Figure 7 Laboratory test of SKL 14 clip: a) Displacement measurement using DIC method; b) Toe force-displacement curves in point P01 (DIC)

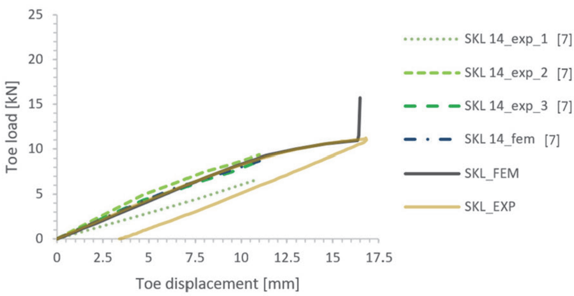

Figure 8 Comparison of the FEA curves and experimentally obtained curves

2.3 CAD model and geometrical parametrisation of the SKL 14 clip

After the FE model validation, the FEA analysis was performed for the modified clips R14 and ScaleX 1.5, where the assigned material model and boundary conditions were the same as for the FE model of the original SKL 14 clip.

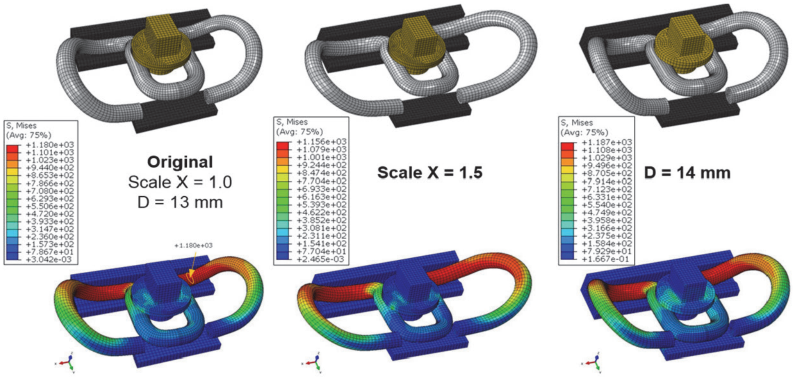

Figure 9 Spatial distribution of stresses in the original and modified clips

By comparing the spatial stress distribution of the original and modified clips (Figure 9) and the obtained force-displacement curves (Figure 10), a change in amplitudes of the stresses and stiffness of the clips can be observed. The ScaleX 1.5 clip showed a decrease in stiffness and a decrease in the maximum amplitude of the stress, and the required clamping force of at least 9 kN was not even reached. On the other hand, for the R14 clip, the force-displacement curve showed an increase in stiffness, and the amplitude of the clamping force of 9 kN is achieved in the elastic area. Slight increase in maximum stress, approximately 7 MPa. For the original clip, the stresses exceeded the yield stress point at a fastening force level of 7,5 kN, which is evident from the curve obtained by experimental testing Figure 8.

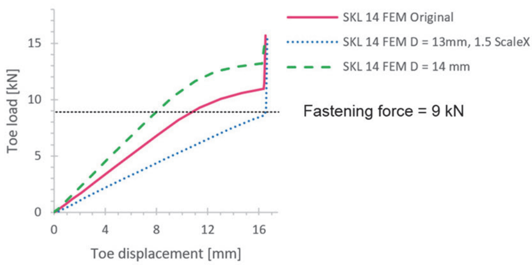

Figure 10 Comparison of force-displacement curves of original and modified clips

3 Conclusion

The parametric study conducted in this paper showed that the presented visual script is suitable for spatial models creation and geometric parametrisation of SKL clips. In that way, computer experiments can be conducted to optimise existing clips. After validation of the FE model, it was clear that such procedures give a good insight into the static behaviour of the clips so that the first assessment of a new or modified clip can be performed. By comparing the original with the modified clips, it was seen that an increase in the diameter of the clip increased the clip stiffness. The amplitude of the fastening force of 9 kN was not achieved in the elastic area for all the analysed clips, and in the case of the original clip, stresses in the rear part of the clip exceeded yield stress that can be avoided by modifying the geometry of the clip. For further research, it is necessary to parameterise all crucial parts of the clip and see how the change in those parameters affects the mechanical behaviour of the clip.

Since the clips are sensitive to fatigue, careful attention should be paid to the amplitude and location of maximum stresses in the clips under all loading cases.

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