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Full-Scale Experiment for Assessing Static Structural and Damping Response of UIC Parabolic Leaf Springs

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Abstract

Over the years, leaf springs have been applied in freight train wagons' systems. Parabolic leaf springs have offered greater guarantees in terms of safety and drivability than classic leaf springs. These leaf springs have intrinsic characteristics that are more attractive, such as lower friction and higher specific energy storage capacity.

In this research, an extensive characterization of UIC parabolic leaf springs is made according to the UIC standard compliance tests. Several types of monitoring devices are used to gather the reaction forces, displacements, relative displacements between leaves in contact, and surface strains.

The outcomes permitted to validation of the numerical model and the suggested approaches.

Keywords: Spring rate, Damping, Relative displacement, Surface stress, Parabolic leaf springs, Railway.

1 Introduction

Over the years, the railway has been a method of collective mobility widely used around the World for small or long distances, in the context of work or leisure. Also, the freight rail sector has also shown its great impact on the world economy, demonstrating to have a big potential to prevent climate change at the same time. With respect to the freight rail sector, efforts have been made to join the previous knowledge about ancient systems and the current knowledge to improve the sector.

Nowadays, in spite of the link suspensions being century-year systems, they have been still used. Parabolic leaf springs are often found in these kinds of suspension systems, once they have been demonstrated to be safer and provide a better-quality wagon motion (see Figure 1). One reason for providing a better-quality motion is because the design of spring was designed in order to reduce friction. Also, its optimized geometry permits it to reach higher specific energy storage capacity with a significant reduction of its own weight.

Figure 1 – Link suspension system with a parabolic leaf spring in a freight wagon.

The determination of the spring rate and friction damping of leaf springs from monotonic bending tests is not trivial. In order words, it is necessary to identify the parcel regarding the elastic work and the parcel with respect to damping work. Also, distinct and dispersed friction coefficients in leaf springs can be found accordingly [1,2].

The present paper intends to characterize the elastic spring rate and friction damping in parabolic leaf springs using a test rig with a trolley arrangement in accordance with UIC [3]. An experimental setup is developed to perform the experiments. Additionally, a numerical model based on finite element method formulation is built. The optimal friction coefficient is found using the golden-section method integrated into a finite element method procedure. Taking the advantage of this compliance bending testing setup, displacement transducers are introduced into the experimental setup to measure the horizontal displacement. Additionally, the relative displacement between in-touch leaves is recorded using a video camera. At last but not least, by introducing strain gauges into the experimental campaign, the stress distribution along leaves' length is collected.

2 Methods

Experimental Apparatus

A full-scale experimental test in parabolic leaf springs was conducted in accordance with UIC 517 OR standard to evaluate the spring rate and friction damping. The overall view of the experimental setup is based on a rig test with a trolley arrangement is illustrated in Figure 2 - A.

The testing machine consists of fixing the leaf spring to the forks through the eyes and applying the load in the central area through a hydraulic cylinder. As the leaf spring is loaded, the ends tend to slip along the guide.

The experiment was run at 0.28 mm/s to ensure no dynamic and inertial effects are introduced into the experiments. A load cell and LVDT are used to measure the vertical displacement. The relative displacement between adjacent faces is measured by tracking the relative position of initial traces (Figure 3 – B). Strain gauges are glued on strategic spots on the top surface of the leaf spring (Figure 3 – C). The horizontal displacement is gathered using two LVDTs installed on each side (Figure 3 – D).

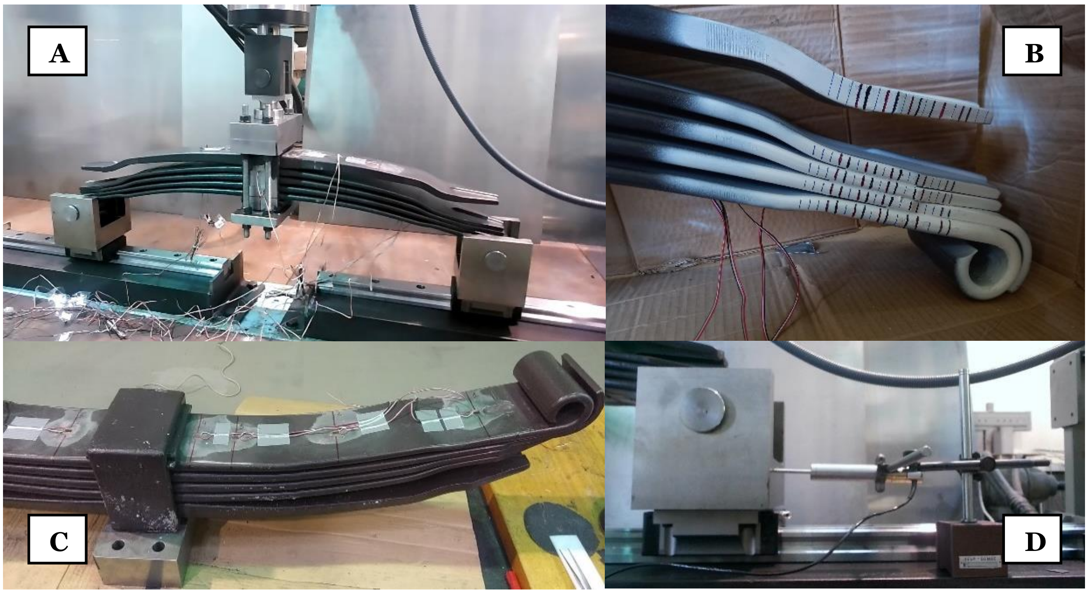

Figure 2 – Experimental setup developed according to UIC rig test with a trolley arrangement. A – Overall view; B – Painting with transversal lines to measure the relative displacement; C – Strain gauges installation on the top surface of master leaf; D – Measurement of horizontal displacement by using LVDT.

Framework for a Numeric Approach

The construction of the geometric model was carried out for every single leaf and other components. The determination of thickness variation and the respective cross-section has been made. Once the CAD model is developed, a finite element mesh with quadratic tridimensional solids is generated as illustrated in Figure 3. The number of hexahedral finite elements is dominant regarding the pyramid and tetrahedral elements. With respect to contact elements, these are quadratic.

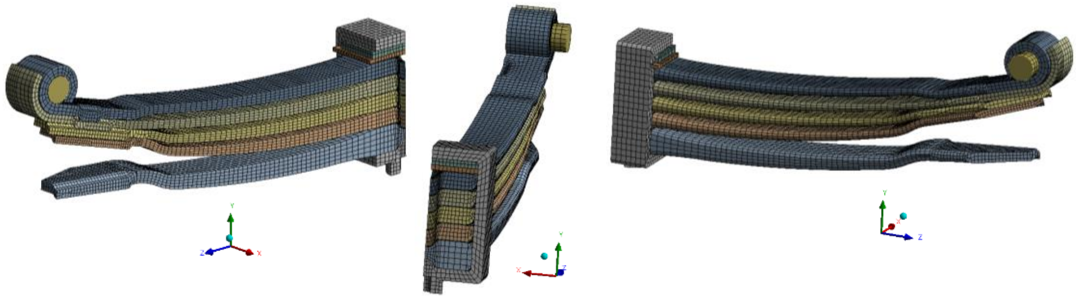

Figure 3 – Graphical interface of FEM model converted from CAD model.

The constitutive relationship for all components is isotropic linear given by Hooke's law (E = 202GPa, ν = 0.29 for leaves and E = 200GPa, ν = 0.30 for the rest of components). The algorithm for large deflection formulation is introduced in the solution scheme. Regarding the contact problem, the Augmented Lagrangian Nested Algorithm is considered [4].

3 Results

Monotonic bending tests were running in displacement-controlled conditions until a maximum force of 80 – 85 kN. The displacement value is enough to evaluate the two stages of leaf spring operating.

Damping and Spring Rate

From Figure 4 – A, one verifies that there is an increase in stiffness when the auxiliary leaf starts acting. Besides, even for leaf springs presenting distinct stiffness change distances, the stiffness for both stages is practically equal. Comparing experimental curves with the numerical curve, there is a good agreement in terms of overall behavior. If no friction is considered in the numerical model, the spring rate is within the hysteresis loop.

Assessing the relationship between horizontal and vertical displacement, one verifies from Figure 4 - B a nonlinear relationship.

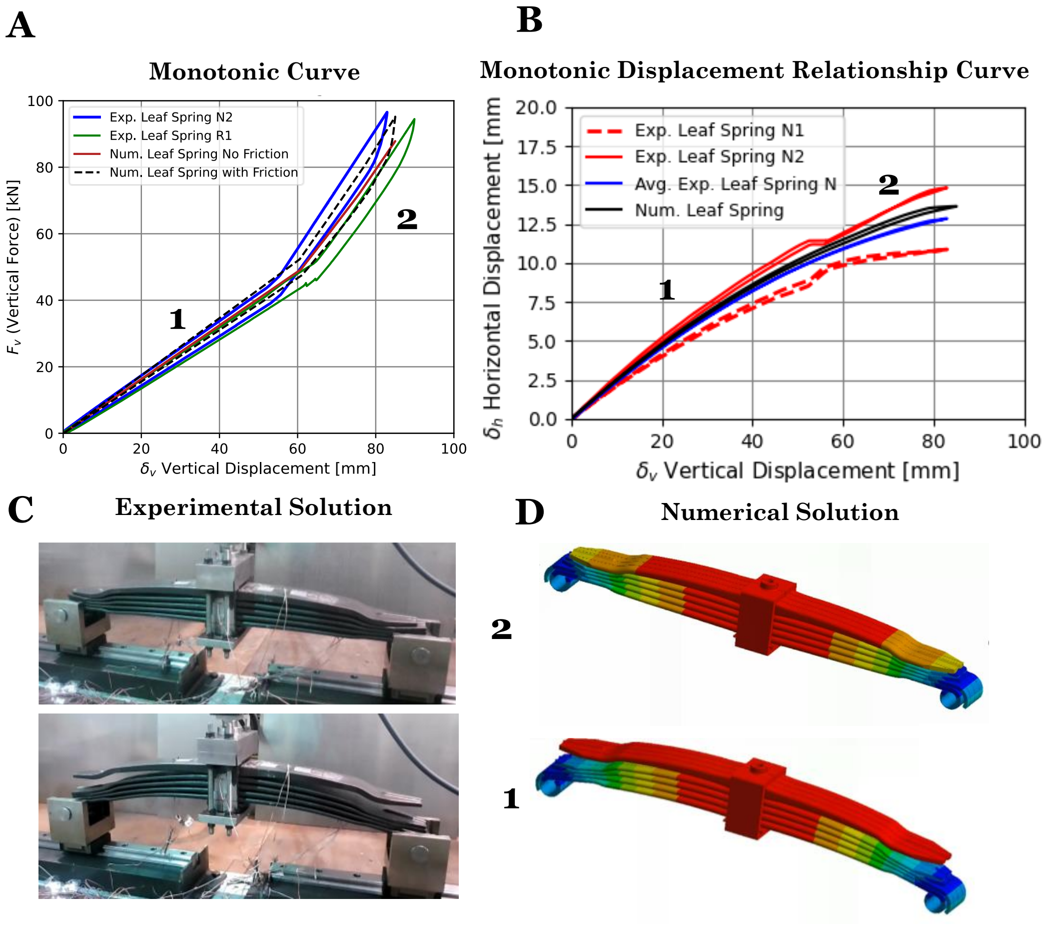

Figure 4 – Monotonic behaviour: A - Stiffness; B – Relationship between vertical and horizontal displacement; C and D – Stage II and I of bending testing.

Relative Displacements on Contact Surfaces

The main leaf has a contribution to the initial damping in stage I as presented in Figure 4 – A. The images permit to make the verification of the existence of displacement between leaves with a maximum value of 4.00mm at the time of 5.00 min.

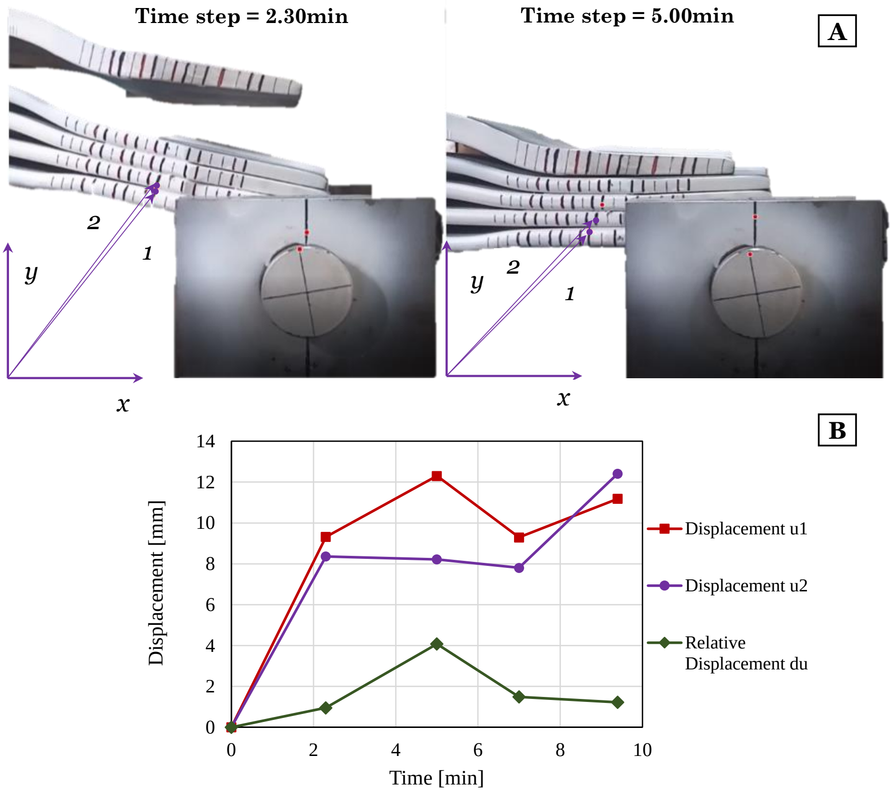

Figure 5 – Relative displacement. A – Images at times 2.30 and 5.00 min; B – Displacement of points 1 and 2 and relative displacement between them.

The relative displacement is computed by equation (1):

$$\Delta u = |u_2 - u_1| \tag{1}$$

with u_i, the Euclidean distance:

$$u_i = \sqrt{(x_i^j - x_i^k)^2 + (y_i^j - y_i^k)^2}, i = 1,2;\ j,k = 1, \dots, n_t, and\ j < k \tag{2}$$

Longitudinal Stress Distribution at Surface of Master Leaf

Once the master leaf is investigated because it is the critical part. Considering the Hooke's law, and neglecting the effect of Poisson's ratio:

$$\sigma_{zz} = E\varepsilon_{zz} + \frac{\nu}{E}\left(\sigma_{xx} + \sigma_{yy}\right) \Leftrightarrow \sigma_{zz} = E\varepsilon_{zz} \tag{3}$$

In Figure 6 – A, the maximum longitudinal stress occurs at strain gauge 3. Additionally, numerical outcomes are a good agreement.

Analysing the whole test and the longitudinal stresses following the path (Figure 6 – B), the maximum longitudinal stresses always occurred in the middle of the leaf. As the loading increases, the maximum tends to be at 0.6 of the total length (see Figure 6 – C).

Comparing the analytical formulation (equation (4)) with numerical outcomes for three loading levels, there is a good agreement.

$$\sigma_{zz} = \frac{F}{n_{leaves}} \frac{(L-z)}{I_{xx}} y \tag{4}$$

The difference is due to the compressive stresses due to the spring buckle (see Figure 6 – D) as expected [5].

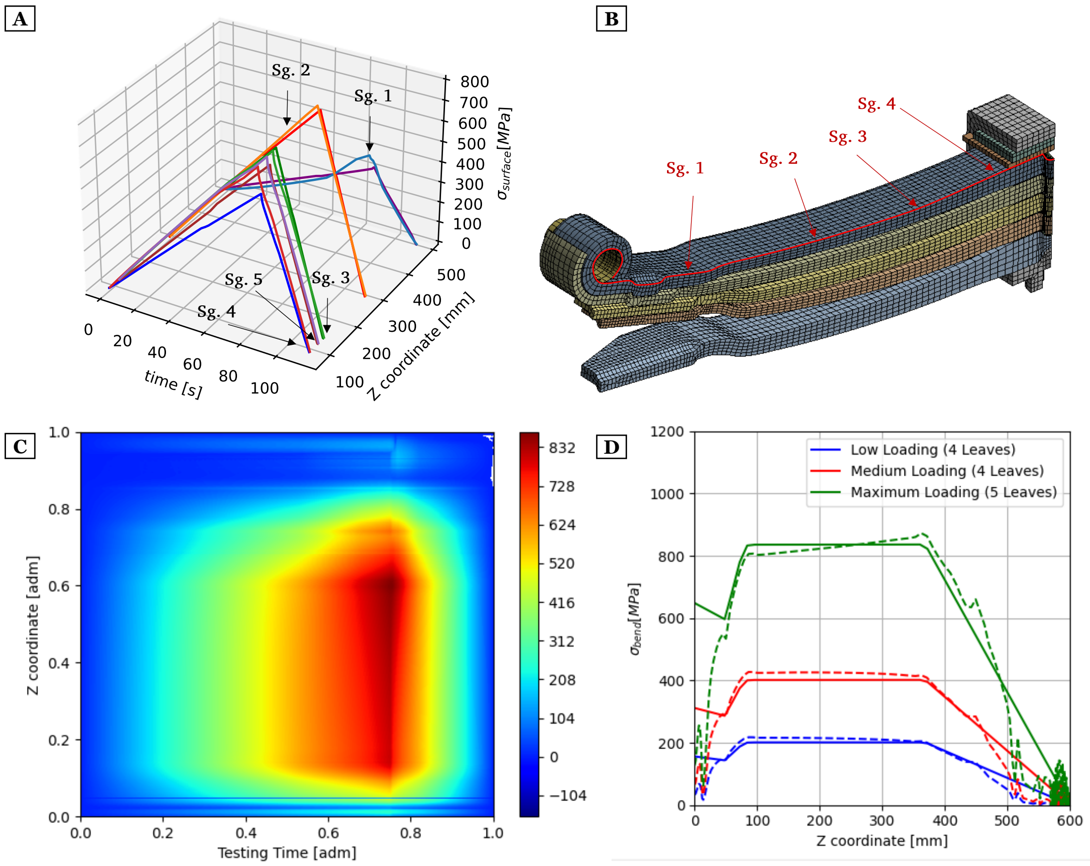

Figure 6 – Longitudinal stress distribution; A – Strain gauge's data and numerical outcomes; B – strain gauges' position and chosen path; C – Variation of stress during the test; D – Application of analytical model.

4 Conclusions and Contributions

The research work described in this paper is intended to investigate the mechanical behaviour of parabolic leaf springs applied in freight train wagons. Additionally, the experimental outcomes permit the validation of the numerical model which will use in future analysis.

The main remarks can be enumerated:

- The numerical model showed a good agreement with the experimental model, in terms of spring rate, damping of the leaf spring, and horizontal displacement on boundary conditions;
- The experiment with respect to the relative displacement was shown to be significant. By our analysis for a displacement of 80mm, a relative displacement of 4mm, approximately was obtained;
- In terms of stress level observed from strain gauges, the numerical model can reproduce the experiment outcomes;
- The maximum longitudinal stress has always occurred in the middle part of the leaf spring until 85mm of imposed displacement;
- The analytical formulation permits reproducing the stress distribution, only at spots non-covered by spring buckle. In addition, at surface spots covered by spring buckle, the analytical model is conservative.

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