Opponent's review of Doctoral Thesis

Candidate:	Ing. Petr Vnenk
Opponent:	doc. Ing. Otto Plášek, Ph.D.
Title of doctoral thesis:	Methodology of Thermal Stress Determination in Continuous Welded Rail
Field of study:	Transport Means and Infrastructure
Study programme:	Technique and Technology in Transport and Communications

The presented doctoral thesis of Ing. Petr Vnenk is focused on the behaviour of continuous welded rail, particularly on the changes of axial forces arising in the track due to temperature changes in the rails.

The thesis is 307 pages long, of which the text of the thesis, including references, is 106 pages. The text of the thesis is organized into the necessary formal chapters, with the text itself organized into six chapters (including the introduction and conclusion). The thesis also has seven appendices summarizing the results of measurements and analyses. Formally, the doctoral thesis contains all the requirements.

Topicality of the doctoral thesis theme

The doctoral thesis focuses on a current topic, which is the safety and reliability of continuous welded rail. The topicality of the topic results mainly from the fact that virtually all reconstructions and new constructions of railway lines involve the establishment of continuous welded rail.

Research works focused on monitoring axial forces in continuous welded rail have been carried out practically for the whole time that continuous welded rail has been applied in railway construction. The technologies for monitoring these axial forces are appropriate to the time in which the research work was and is being carried out. Up to this time, no simple and reliable way has been found to determine the axial forces in continuous welded rail from temperature changes and other influences. This is confirmed in the present doctoral thesis, where the author discusses this problem in detail in a review of the current state of knowledge.

Fulfilment the doctoral thesis objectives

The definition of the doctoral thesis objectives is included in Chapter 1 Introduction. The defined objectives were:

- to investigate current knowledge in the field of CWR stress determination,
- to identify important parameters influencing rail temperature and quantify their impact,
- to develop a methodology of non-destructive CWR thermal stress determination.

The third defined objective was, in fact, the final objective of the whole doctoral thesis. Therefore, also within the chapter focused on the objectives, the methodology that was selected to achieve the objective was defined.

It should be noted that the overall aim of the doctoral thesis was quite ambitious. It has not yet been possible to develop a reliable and sufficiently accurate method to determine non-destructively the internal axial force in a continuous welded rail or in individual rails.

However, given that the author of the thesis was aware of this and the research uncertainty was considerable in this case, the objective was defined rather more generally without any particular claims on the practical applicability of the developed methods.

I consider the stated objectives of the doctoral thesis to have been fully met.

Approach to the implementation, results achieved, specific contribution of the student

The basic methods of the doctoral thesis were defined in the same chapter as the doctoral thesis objectives. The first chapters of the thesis include a description of the current state of knowledge, a theoretical description and a basic analysis of strain, stress and forces in the frictionless track, its middle part and the breathing end (zones). The second part of the thesis, in my opinion very useful, focuses on the connection between the temperature of the rails and the climatic influences acting on them. The third part of the thesis is focused on the theoretical description of the selected methods of monitoring the continuous welded rail and verification in laboratory conditions. The fourth part of the thesis is then focused on the measurement in-situ, its instrumentation, measurement results and their evaluation and analysis. I consider the selected methodology of the doctoral thesis to be appropriate.

The PhD student achieved significant results in his experimental work, both in the laboratory and in the in-situ measurements. I consider the results of his in-situ measurements to be excellent, and they can become the basis for further research activities. It should be noted here that the measurements within the doctoral thesis only cover a short period in terms of the lifetime of specific continuous welded rail structures. Further monitoring of the instrumented sites in the future will certainly provide further important insights into the behaviour of continuous welded rail.

From the text itself and from my personal experience gained during the publication of the results of the work so far, it is clear that the PhD student is the author of the methodology and has implemented the presented measurements as the lead researcher of the partial research tasks. I consider the specific contribution of the PhD student to be essential.

Importance for practice and for the development within a branch of science

In my opinion, the submitted doctoral thesis represents a significant contribution to practice and the scientific field's development.

As far as practice is concerned, here, I consider the results of the measurement and analysis of the results to be particularly significant. The total number of sites surveyed, and the measuring points installed in them are impressive. Of course, further insight into the issue of axial forces and their changes along the length of the track due to different climatic influences, different directional and inclination arrangements of the track, different superstructure designs and different operating conditions will be provided by long-term monitoring over many years. Even so, the current interpretation of the results is important for the infrastructure manager.

Theoretical analyses and laboratory experiments support the methodology for in-situ monitoring of the strain of rails. These results deepen our knowledge and provide additional insights for applying this tracking method for future research work.

Specific comments and questions

On the content of the doctoral thesis itself, I have specific questions for discussion during the defence:

- Ch. 3: The problem is always the temperature measurement of the rails. The temperature varies along the rail section and needs to be measured at multiple points. How has this measurement problem been solved?
- Ch. 2.3.4, Measurement of Magnetic Barkhausen Effect: What is the measurement error achieved?
- Ch. 3.2.3, Fig. 3.35: There is a noticeable reduction in temperature fluctuation between November 2022 and March 2023. What can explain this?
- Ch. 4.1.2 Thermal Loading of Sample Fixed at Both Ends, Fig. 4.6: If the sample were completely fixed, between supports, no strain could be measured by the strain gauges. This is probably due to the clamping between the hydraulic cylinders, which cannot be locked. Please clarify (similarly also Figure 4.8). The discussion at the end of the chapter is also related to this.
- Ch. 5.2, paragraph under relation 5.1: The negative value of the coefficient a could be since there are always phenomena in the track that lead to a reduction of the axial force during temperature rise (small lateral deflections of the rails, displacement of the track in the lateral direction, etc.). I ask the candidate for his opinion.

Other minor specific comments:

- Ch. 2: A very interesting overview of the methods used to measure the forces (stresses) in rails is given. However, there are many missing descriptions of the measured physical quantities and their relation to the determined internal forces, the principle of the sensors, and the relationships between the quantities.
- Ch. 2.2, Eq. 2.3: I miss the definition of the sign convention ΔT with respect to equations below.
- Ch. 2.2, Eq. 2.6: The above equation is a general expression for the local extremes of functions, here the function of the displacement of the rails (track) along its length. Thus, the equation does not define the location of the absolute extreme. Considering the complexity of the progression of axial forces along the length of the track and their time dependence, I would recommend a more general definition here, e.g., the middle part of a continuous welded rail.
- Ch. 2.2, clarification under Eq. 2.23: The equation for R_x is probably not correct, only the sign should have been taken for ΔT.
- Ch. 2.3.1, Measurement with Brillouin Optical Time-Domain Reflectometry: neither the physical principle nor the sensed quantities are clear from the text.
- Ch. 2.3.2, VERSE Methodology: lacks the expression of the principle by means of basic relations. Regarding the disadvantages of the method, I believe that also the forces in the CWR in the stretched section will affect the neutral temperature.
- Ch. 2.4.2: I somewhat lack a discussion of the stresses in the rail that arise due to lateral forces – lateral bending and torsion of rail.
- Ch. 3.1: I lack an explanation of the basic modes of thermal conduction and transfer (radiation, conduction, and convection). This would allow a better orientation in the text that follows.

- Ch. 3.1.2: The effect of cloud cover on the differences between air and rail temperatures is discussed. The influence of air velocity (wind) is evident, see also Fig. 3.32.
- Ch. 3.1.3: The specific layout at a given location, the location of the rails (track surface), etc. will certainly have an influence.
- Ch. 3.2.2, Figure 3.22: The results may be affected by the crossing.
- Ch. 3.2.2, Fig. 3.26: The dark surface of the rail throughout the cross section will affect the heat transfer by radiation, see also Table 3.3.
- Ch. 4.3, para. 3: apparent strain measurements are mentioned, but in my opinion, this is not possible. Similarly, chap. 5.2, para. under Fig. 5.5.
- Ch. 5.2, para. 1: It is stated that linear regression is sufficient. This statement could be supported by the qualities of linear and nonlinear regression.

Formal layout of the doctoral thesis and the level of language used

From a formal point of view, I consider the doctoral thesis to be very well prepared. The organization into chapters is appropriate, and the background of the thesis, the methods used, the research activity itself and the results obtained are clear. The scope of the thesis is adequate, and extensive results of measurements and analyses are appropriately presented in the appendices of the thesis.

I cannot assess the language in detail, given that I am not a native speaker. However, the text is clear, easy to read, terminologically correct and contains no major linguistic errors. The number of typos and typographical errors is negligible.

I have the following specific comments on the formal aspect of the thesis:

- The definition of basic terms used in the thesis is somewhat lacking. These definitions contributed to the clarity and unambiguity of the text of the thesis.
- Ch. 2.2, last sentence, gives a temperature range of 5°F, it would be more appropriate to use units of K, or at least °C.
- Ch. 2.3.4, Fig. 2.15: Poorly legible figures reproduced.
- Ch. 2.3.4, Fig. 2.16: The quantity being monitored (dHp(y)/dx) is not explained.

I consider the number of cited sources appropriate to the doctoral thesis's content and scope. In terms of references, I somewhat miss the publications of P. Ryjáček, focused on monitoring the behaviour of continuous welded rail on bridge structures.

Final assessment of the doctoral thesis

I consider the doctoral thesis very beneficial for the practice and development of the scientific field, and its results are very valuable. The submitted doctoral thesis clearly documents the scientific competence of the candidate. In conclusion, I state that the doctoral thesis meets the requirements for a doctoral thesis and after a successful defence

I recommend

the granting of the Ph.D. degree.

Brno, 29 October 2022

doc. Ing. Otto Plášek, Ph.D.