Assoc. Prof. Piotr Chrostowski, Ph.D

Faculty of Civil and Environmental Engineering
Department of Transportation Engineering
Gdansk University of Technology

02.11.2022 r.

Review of dissertation entitled:

„Methodology of Thermal Stress Determination in Continuous Welded Rail"

Author: Petr Vnenk
Supervisor: Assoc. Prof. Bohumil Culek, Ph.D.

1. Formal basis, subject, and purpose of the review

1.1 Formal basis

The Department of Transport Structures commissioned the review in a letter of 27 September 2022. This letter was issued under the decision of the Advisory Board of the Doctoral study program "Transport Means and Infrastructure" at the University of Pardubice, Faculty of Transport Engineering.

1.2 Subject of review

The subject of the review is the doctoral dissertation written by Petr Vnenk entitled Methodology of Thermal Stress Determination in Continuous Welded Rail.

The dissertation was prepared on the Faculty of Transport Engineering at the University of Pardubice under the supervision of Assoc. Prof. Bohumil Culek, Ph.D.

This dissertation was submitted for review in digital form (PDF format), containing 307 numbered pages in A4 format.

The Author's biogram and a paper presenting the main achievements of the research work (a short version of the dissertation) were also received. However, only the **complete version** of the doctoral dissertation was formally assessed within the review.

1.3 The purpose of the review

The purpose of the review is to determine whether the submitted dissertation meets the requirements in accordance with § 47 of the Higher Education Act No. 111/1998. The Author's contribution to the state of science in the field of Transport Engineering will be assessed in order to determine the legitimacy of the author's application for the Ph.D. (philosophiæ doctor).

2. Subject matter and the structure of the dissertation

2.1 Assessment of dissertation's subject matter

The reviewed work concerns (according to its title) the issue of determining the level of thermal stress in rails of Continuous Welded Rail (CWR) track.

This issue is directly related to railway maintenance and track operation (reliability, safety). Axial force in rails leads to permanent displacements of the track in both longitudinal and transverse directions. These dislocations can be unexpectedly rapid and cause a high risk of rail breaking/buckling which can result in a train derailment.

The complete solution of the stability problem in the way of theory only is extremely difficult, due to the fact, that the characteristics of the railway superstructure, as well as subgrade, are mostly non-linear and changeable in time and spatial domain as well. Therefore, the process of risk determining regarding a loss of stability is usually complex and requires both theoretical analysis and difficult field measurements. All this means that efficient techniques for determining the CWR track parameters are still sought after all over the world.

The study concentrates on the method of determining one of the most important parameters influencing the operation of the CWR track, i.e. stress due to rail temperature changes. Thermal stresses make an important contribution to the overall stress level of a rail. Additionally, the determination of their values is subject to the uncertainty of the reference level, which is defined as the neutral temperature. Determining the value of the neutral temperature along the length of the railway track is an important and difficult issue in the context of maintaining railway lines. For this reason, the research subject matter undertaken by Petr Vnenk is fully justified and is of very great cognitive as well as utilitarian potential.

2.2. Characteristics and evaluation of the dissertation structure

The reviewed work consist of six numbered chapters included in the table of contents, preceded by the List of Figures, List of Tables, List of Abbreviations, Acknowledgments, and a summary (in Czech and English). The layout of the chapters is closed with Literature, followed by a number of appendices (A-G), and the final annex presents a separate work describing in detail a methodology directly related to the submitted dissertation.

Chapter 1, entitled ***Introduction*** provides a short (3 pages long) explanation of the main sense and motivation for the research undertaken. This chapter presents the scope of the work in a concise way. The main goals and contributions to the work were defined. A scientific research project is indicated, the author of which has been the principal investigator.

Chapter 2, ***Current Knowledge***, is 21 pages long. It contains the basic analytical assumptions related to the CWR constant (central/fixed) section and breathing ends theoretical models, in particular the relationships between the normal stresses in the rails of the railway track and the temperature, the change of which concerning the previous state is proportional to the thermal stresses. Equations in differential form were derived. This chapter defines an analytical model that will be subsequently applied in the analysis of empirical data. The rest of this chapter is devoted to a short description of the methods of the neutral temperature experimental investigation, the identification of which is crucial to estimate the actual state of the stress or axial force in the CWR track. The methods have been briefly assessed regarding their usefulness aspects in track maintenance.

Chapter 3, entitled ***Rail Temperature***, has 26 pages. In this section, the Author described the original concept of determining the rail temperature based on the collected meteorological data. The proposed method consists in examining the correlation between the selected parameters and the sought rail temperature. In this chapter, the assumptions, the course of experiments, and the results of model identification from the data approximation have been presented. The chapter ended with a short discussion of empirical results in relation to the calculated with the use of developed theoretical models ones.

Chapter 4, entitled ***Strain of Continuous Welded Rail***, is described within 20 pages.

This chapter begins with a description of experimental studies carried out under laboratory conditions. The main purpose of these experiments was to examine a measuring system using Wheatstone Bridge, which, using strain gauges, allows a determination of the deformation of the tested structure element subjected to a variable thermal field. The applied method takes into account the influence of the temperature of strain gauges and its influence on the results. The final aim of these studies was to develop a measurement system suitable for field experiments. Subsequently, the description of the field research has been introduced. The characteristics of the experimental sections together with the assembly of measuring devices have been presented in detail. This section ended with the measurement results presentation.

Chapter 5, ***Neutral Temperature Development of Continuous Welded Rail***, is 25 pages long.

This chapter is devoted to the analysis of the results of rail strain measurements in the chosen evaluation locations along the investigated tracks. The analysis consisted in determining the real thermal stress as the instantaneous value, taking into account the varying neutral

temperature in the particular spot. Therefore the determination of the change of the rail neutral temperature was indicated as a main goal of the measurement data processing. This chapter corresponds to the main achievement of the research work as it links the previously established theoretical assumptions with experimental field research. The results were assessed qualitatively and quantitatively, mainly in terms of the statistics of the parameter responsible for determining the neutral temperature changes.

Chapter 6, entitled ***Conclusions***, covers 2 pages.

The References section lists the bibliographic positions cited in the dissertation. The list contains 61 references presented in citation order.

Subsequently, seven appendices containing mainly the results of measurements and analyzes, as well as a detailed description of the determination of measurement uncertainties (Appendix B) are included. The titles of the attachments are listed below:

A Rail Temperature Recordings 107

B Measurement Uncertainty Determination

C CWR Strain Recordings

D Relation of Strain and Temperature

E Development of Measured and Extrapolated Temperature Difference

F Comparison of Temperature Differences per Cross-Sectional Proles

G Comparison of Standard and New Approach to the Thermal Stress Determination in CWR

The final part – Annexes, is a separate set of documents that present a detailed methodology description utilized in this dissertation, as well as deliver a document that approves the methodology in a form of a Certificate of Approval of the Methodology. The Author is pointed as an author of this methodology.

The structure of the work also includes a List of Figures, a List of Tables, a List of Abbreviations, and Acknowledgments.

The entire dissertation has been composed clearly in a consequent manner. The chapter's arrangement is well thought out and leads from assumptions throughout the practical realization toward the evaluation of research results. All experiments were thoroughly described in detail and illustrated with photos. Also, all of the results were presented using well-formatted and described charts and tables. All equations were correctly commented on and defined and their parameters/variables were fully explained. The layout of the attachments

does not raise any objections. However, some formatting errors occasionally occur within the text. Below I indicate some examples raising my doubts:

- p. 27 - sensor installation is not provided in any photo.

- In figure 3.1, the photo source is not given.

- In table 3.1, there is a lack of standard deviation corresponding to the mean value.

- Figure 3.6 Does the relationship between temperature difference and cloudiness corresponds to the result's table?

- Figure 3.7 The used colors do not correspond to the text.

- Figure 3.36 does not show the azimuth of the line, the description is imprecise. The angles correspond with the perpendiculars to the rail longitudinal axis.

The following comments do not diminish the value of the editorial side of the work. Presented by the Author editorial skill is at a very high level.

3. Assessment of the doctoral dissertation, substantive aspect

In terms of content, I evaluate the work positively. I argue my assessment with the following points:

- Without any doubt, the work is scientific in terms of development and research. It concerns experimental research in a wide field range. The undertaken studies were relatively difficult to carry out due to their territorial scope. Several test sections have been established so that they cover the assumptions regarding the impact of various conditions (like terrain specification) on the potential results. It is an approach characterizing the scientific method, where a wide range of solutions is sought following previous predictions consistent with the theoretical analysis of phenomena.

- The assumptions have been reliably set in the context of the achievements of other researchers. The study of literature has been carried out in a wide range, taking into account the historical and contemporary state of art. This proves the knowledge of the subject of the Applicant.

- The conducted field research was preceded by laboratory investigation and analysis of achieved results, including measurement uncertainties. For this reason, the difficult field measurement appears to be reliable in the context of the methodology of both recording and evaluation of collected data.

- The results analysis was carried out with the use of analytical models. This proves, that the Author fully understands the physical phenomena he investigated under preliminary theoretical assumptions.

- The methodology of determining the (instantaneous) track temperature includes innovative techniques for determining the key parameters. These techniques simplify the measurement process by the correlation study (track's ambient parameters). It is true, that this problem has not been finally solved in the assessed dissertation, however, the actions taken by the Author bring him closer and closer to the solution and further research hopefully will confirm the correctness of these assumptions soon.

4. Critical remarks

Concerning the assessed doctoral dissertation, I present the following general comments.

1. The methodology of field measurements was presented after the study of other methods known from the literature. These methods are using theoretical relationships of various parameters of physical quantities with the stress state of the rail. Each method has been characterized in terms of its practical suitability. The work lacks presented limitations of the proposed Author's measurement method concerning the CWR track characteristics. Has the author analyzed the relationship between the neutral temperature changes and the phenomenon of rail's creeping? Were geometric imperfections of the track taken into account in the stress analysis?

2. The methodology of determining the rail temperature based on meteorological data has been presented as a potential element of the measurement methodology in the context of determining thermal stress. The paper presents several experimental results, however, the actual usefulness of the indirect method of temperature determination was not assessed in detail. The strain measurement as well as the temperature at the designated test points was carried out directly. Therefore, it was possible to carry out the analysis using direct and indirect methods to determine the thermal stresses.

3. The paper presents a comparison of the resulting thermal stress and the ones calculated without taking into account the changes in the neutral temperature during operation. It is not entirely clear, what the specific purpose of such a comparison is. Since the correctness of the method is postulated, it should be referred to an alternative method that estimates the value of the neutral temperature as varying in exploitation time too. The lack of a such comparison element raises questions about this method's validation.

4. The Author presents plenty of graphs illustrating strain changes at measurement points (Appendix C) and also aggregated charts. There is no presentation of such changes concerning the spatial distribution of measuring points. The Author explains this by the methodology of conducting measurements, which is of a serial (sequential) nature. Was there any possibility of such an analysis and presentation of the results in a statistical sense?

5. The way of presentation of the differences in the stress determinations as in the diagrams placed in Appendix G raises some doubts. The comparison does not include fully precise

descriptions of both methods in the context of the comparison. Is the Author sure that these results should be unequivocally compared? The comment to the diagrams is imprecise, it refers to the temperatures, while the stresses are indicated on the vertical axis as the ordinates. It is also confusing to interpret the area under the plot as stresses (gray field between poly-lines). The field should have a unit different from that of the ordinate. The presenting way of the results could be more clearly explained.

5. Conclusion and recommendation

The doctoral dissertation submitted for review and assessment is a valuable scientific work with both cognitive and practical values. The formulated research goals meet the current design and maintenance problems, and the developed methodology was based on the scientific method.

The substantive comments presented in the review do not diminish the scientific significance of the work and can be explained precisely during the public defense. In the assessed work, the Author uses an understandable technical and scientific style, which is relevant to the field of railway engineering and the scientific discipline of transport engineering.

The presented methodology for nondestructive stress determination caused by rail temperature changes may be an effective decision-support tool in the railways maintenance practice. The presented results give a lot of engaging information regarding the influence of many factors on the investigated parameters which are also consistent with engineering knowledge and intuition as well. The assessed research work provides elements of the original methodology and is an added value to the decidedly complex problem which is the maintenance of the CWR track during its operation. The Applicant demonstrates a high level of general knowledge in the scientific discipline related to civil engineering, and what is crucial, the Author's ability to conduct scientific research.

Recommendation:

The submitted dissertation meets the requirements in accordance with § 47 of the Higher Education Act No. 111/1998. Accordingly, I recommend accepting this dissertation for further processing and public defense as well.

Gdańsk, November 2, 2022 Piotr Chrostowski