CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

IRF GLOBAL

FEHRL

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA[2018]
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

CETRA2018
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

ORGANISATION

CHAIRMEN

Prof. **Stjepan Lakušić**, University of Zagreb, Faculty of Civil Engineering
Prof. emer. **Željko Korlaet**, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. Stjepan Lakušić
Prof. emer. Željko Korlaet
Prof. Vesna Dragčević
Prof. Tatjana Rukavina
Assist. Prof. Ivica Stančerić
Assist. Prof. Maja Ahac
Assist. Prof. Saša Ahac
Assist. Prof. Ivo Haladin
Assist. Prof. Josipa Domitrović
Tamara Džambas
Viktorija Grgić
Šime Bezina
Katarina Vranešić
Željko Stepan
Prof. Rudolf Eger
Prof. Kenneth Gavin
Prof. Janusz Madejski
Prof. Nencho Nenov
Prof. Andrei Petriaev
Prof. Otto Plašek
Assist. Prof. Andreas Schoebel
Prof. Adam Szeląg
Brendan Halleman

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Stjepan Lakušić, University of Zagreb, president
Borna Abramović, University of Zagreb
Maja Ahac, University of Zagreb
Saša Ahac, University of Zagreb
Darko Babić, University of Zagreb
Danijela Barić, University of Zagreb
Davor Brčić, University of Zagreb
Domagoj Damjanović, University of Zagreb
Sanja Dimter, J. J. Strossmayer University of Osijek
Aleksandra Deluka Tibljaš, University of Rijeka
Josipa Domitrović, University of Zagreb
Vesna Dragčević, University of Zagreb
Rudolf Eger, RheinMain Univ. of App. Sciences, Wiesbaden
Adelino Ferreira, University of Coimbra
Makoto Fujiu, Kanazawa University
Laszlo Gaspar, Széchenyi István University in Győr
Kenneth Gavin, Delft University of Technology
Nenad Gucunski, Rutgers University
Ivo Haladin, University of Zagreb
Staša Jovanović, University of Novi Sad
Lajos Kisgyörgy, Budapest Univ. of Tech. and Economics
Anastasia Konon, St. Petersburg State Transport Univ.
Željko Korlaet, University of Zagreb
Meho Saša Kovačević, University of Zagreb
Zoran Krakutovski, Ss. Cyril and Methodius Univ. in Skopje
Dirk Lauwers, Ghent University
Janusz Madejski, Silesian University of Technology
Goran Mladenović, University of Belgrade
Tomislav Josip Mlinarić, University of Zagreb
Nencho Nenov, University of Transport in Sofia
Mladen Nikšić, University of Zagreb
Andrei Petriaev, St. Petersburg State Transport University
Otto Plašek, Brno University of Technology
Mauricio Pradena, University of Concepcion
Carmen Racanel, Tech. Univ. of Civil Eng. Bucharest
Tatjana Rukavina, University of Zagreb
Andreas Schoebel, Vienna University of Technology
Ivica Stančerić, University of Zagreb
Adam Szeląg, Warsaw University of Technology
Marjan Tušar, National Institute of Chemistry, Ljubljana
Audrius Vaitkus, Vilnius Gediminas Technical University
Andrei Zaitsev, Russian University of transport, Moscow

CETRA[2018] 17–19 May 2018, Zadar, Croatia
5th International Conference on Road and Rail Infrastructure

THEORETICAL-CALCULATION MODEL FOR DETERMINATION ON STRESS AND LOAD-BEARING CAPACITY IN RAIL-TRACK WITH CORROSION

Antonio Shopov
Technical University of Sofia, Bulgaria

Abstract

The researches, connected with the clarification of the influence of the corrosion over the stress and the capability of carrying weight are a key-factor for the correct evaluation of the state of the elements. All the rails are practically subjected to the influence of the atmosphere, so all of them are under the effects of the atmospheric corrosion, which can have three different aspects – reduction of the geometrical characteristic of the section appearance of surface defects (structural changes) and decrease of the mechanical properties. In this study, we present a theoretically calculated module to determine the factual borders of the stress and the possibility of carrying weight of a rail track with corrosion (type “continuous beam”). Dependencies are derived and computational algorithms with calculations and numerical realisation as well.

Keywords: corrosion, continuous beam, rail-track, stress, load-bearing capacity

1 Introduction

There are numerous railroads in many countries, which have been built more than fifty years ago. Throughout the years, these railroads are subjected to corrosion, irrelevant of whether they are used or not. We already know – there are different types of corrosion (atmospheric, chemical, alkaline, electro-chemical etc.) [1]. The atmospheric corrosion exerts in fact permanent influence over the rails and this leads to the change of the geometrical characteristic of the section, to the appearance of defects on the surface (structural changes) and to the worsening of their mechanical properties [4], [5] etc.
On figure 1 we have shown a rail which has not been used at all for more than 25 years, while on figure 2 we have shown a rail track on which daily (in an interval of 5-10 minutes) there pass motor cars of the subway.

Figure 1 General view

Figure 2 General view over the rail

It is quite obvious that there is corrosion on both types of rails, irrelevant of the fact that one of them is in the open air, while the other is inside a subway station. What is doubtless is that the main factor, influencing them, is the atmospheric corrosion. We have to determine now what the influence is of the corrosion over the stress and the capability of carrying weight of the rail, concerning its maximal use and/or its repeated use with the idea to clarify until which moment it would be capable of exploiting.

2 Setting a task

We have observed a steel rail of the type 60 E1, used on sleepers deployed on a 50 cm interval, which has been calculated for a maximal bending moment under weights with already familiar characteristics and density. We would like to see the changes of the stress and the deformities at any given moment of the free development of its corrosion and the moment the border value will be reached will define the factual capability of carrying weight of the corroded rail track.

3 A theoretically calculated module

We have observed a 12 meters long rail-track with section of the type 60 E1, Figures 3 and 4.

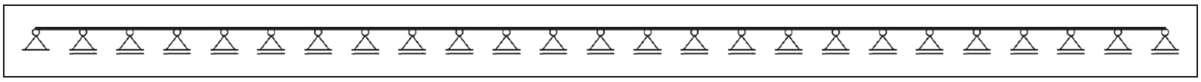

Figure 3 Theoretical static scheme of type "continuous beam"

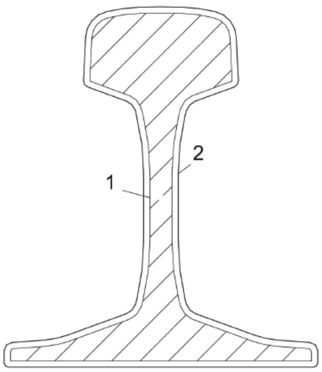

Figure 4 Rail track section (1-non-corroded part, 2-corroded part)

Having used the hypothesis of Bernoulli about the platitude of the sections [3], we have described the deformation as a linear function with two parameters, as other researchers do [7] and [8], so we can express the strain as:

$$\varepsilon_x = \alpha_1 + \alpha_2 \cdot z \tag{1}$$

Then the normal stress is written:

$$\sigma_x = (\alpha_1 + \alpha_2 \cdot z) \cdot E \tag{2}$$

We can determine the stress according to the formula:

$$N(x) = \int_{A_1} \sigma_x dA + \int_{A_2} \sigma_x dA = 0 \tag{3}$$

$$M(x) = \int_{A_1} \sigma_x \cdot z dA + \int_{A_2} \sigma_x \cdot z dA = M(x) \tag{4}$$

The internal stress in any given section should be defined as follows:

$$N(x) = E \cdot \int_{A_1} (\alpha_1 + \alpha_2 \cdot z) dA + \int_{A_2} E_2(z) \cdot (\alpha_1 + \alpha_2 \cdot z) dA = 0 \tag{5}$$

$$M(x) = E \cdot \int_{A_1} \left(\alpha_1 \cdot z + \alpha_2 \cdot z^2\right) dA + \int_{A_2} E_2(z) \cdot \left(\alpha_1 \cdot z + \alpha_2 \cdot z^2\right) dA \tag{6}$$

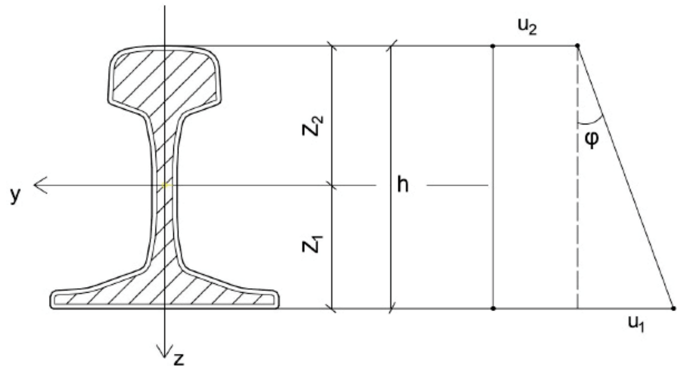

Figure 5 Determine the transformation

We have to determine the transformations – see Figure 5 and we note:

$$u_1 = (\alpha_1 + \alpha_2 \cdot z_1) dx \tag{7}$$

$$u_2 = (\alpha_1 + \alpha_2 \cdot (-z_2)) dx \tag{8}$$

$$-\frac{d\varphi}{dx} = \frac{u_1 - u_2}{h} = \frac{(\alpha_1 + \alpha_2 \cdot z_1 - \alpha_1 - \alpha_2 \cdot (-z_2))}{h} = \frac{\alpha_2 \cdot (z_1 + z_2)}{h} = \alpha_2 \tag{9}$$

The Eq. (5) and Eq. (6) can be presented as a system in the following way:

$$\left| \begin{array}{l} a_{11} \cdot \alpha_1 + a_{12} \cdot \alpha_2 = b_1 \\ a_{21} \cdot \alpha_1 + a_{22} \cdot \alpha_2 = b_2 \end{array} \right. \tag{10}$$

Where:

$$a_{11} = E \cdot A_1 + \int_{A_2} E_2(z) \cdot dA \quad ; \quad a_{12} = a_{21} = E \cdot S_{y1} + \int_{A_2} (E_2(z)) \cdot z \cdot dA \quad ; \quad b_1 = 0$$

$$a_{22} = E \cdot J_{y1} + \int_{A_2} (E_2(z)) z^2 \cdot dA \quad ; \quad b_2 = -M(x) \quad ; \quad S_{y1} = \int_{A_2} z \cdot dA \quad ; \quad J_{y1} = \int_{A_2} z^2 \cdot dA$$

α_1 – stress when z = 0;
α_2 – according to Eq. (7) and Eq. (9);
A_1 – area of non-corroded part;
A_2 – area of corroded part;

We have to use the basic principle that:

$$w'(x) = tg\varphi \approx \varphi = \frac{dw}{dx} \quad ; \quad w''(x) = \frac{d\varphi}{dx} = -\alpha_2 \tag{11}$$

Accordingly, there follows:

$$\varphi(x) = -\int \alpha_2 dx = -\alpha_2 \cdot x + C_1 \tag{12}$$

$$w(x) = -\alpha_2 \cdot \int x dx + \int C_1 dx = -\alpha_2 \cdot \frac{x^2}{2} + C_1 \cdot x + C_2 \tag{13}$$

The permanent values C_1 and C_2 are at the borders of the respective conditions, i.e.: w (0) = 0; C_2 = 0; w' = f_1 (0); C_1 = f_1 (0); w (l) = 0.

Having in mind all these dependencies, we can proceed with numerical realisation. The locomotive of the type V100 (diesel) was placed on a corroded rail – Figure 5. We have used the model of Birman [2] (Figure 6) and the forces upon which the rail be influenced are shown on Figure 7. With the help of the theorem of three moments (Clapeyron's theorem) we have prepared the M-diagram – Figure 8.

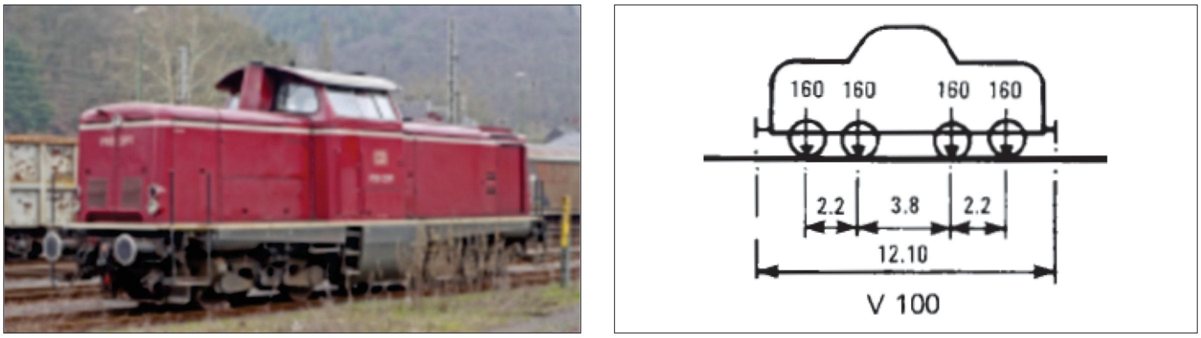

Figure 6 Locomotive V100 on corroded rail (left); model of Birman (forces) [2] (right)

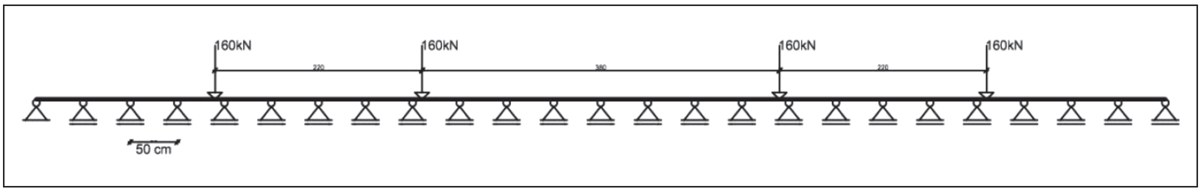

Figure 7 The forces upon which the rail

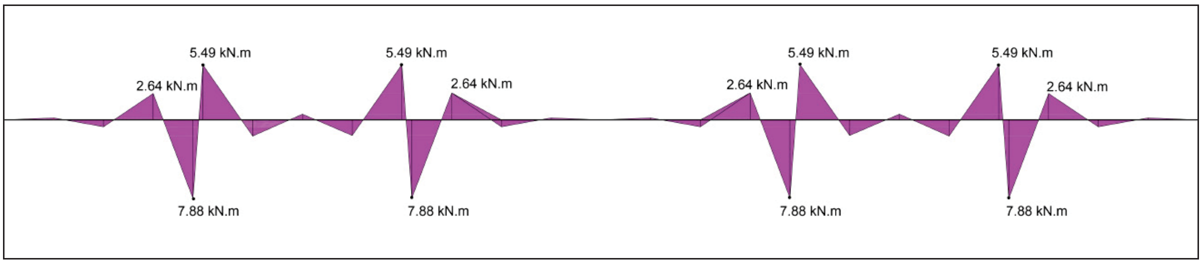

Figure 8 M-diagram

We have used a method of determining the constant value C_1, for the increase of the value, which involves the application of different values, so we have marked the dependency:

$$w_i = w_{i-1} + \frac{dw}{dx} = w_{i-1} + w'dx \tag{14}$$

i.e. we provide with an initial step f=1.10^{-16}, dx = 2 cm (Figure 9 and Figure 10), until the fulfilment of the starting and the bordering conditions of each point on the rail i.e.

$$\left| \begin{array}{l} a_{11}\cdot\alpha_1 + a_{12}\cdot\alpha_2 - b_1 = 0 \\ a_{21}\cdot\alpha_1 + a_{22}\cdot\alpha_2 - b_2 = 0 \end{array} \right. \tag{15}$$

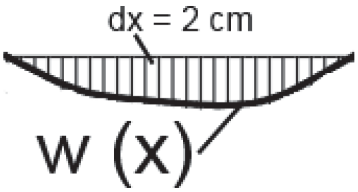

Figure 9 w(x) principal diagram, part dx=2 cm (mesh), l=50 cm

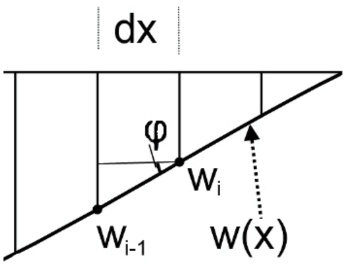

Figure 10 w(x) principal diagram, part dx=2 cm (mesh), step f=1.10^{-16}

Calculation baseline data:
M = 7.88 kNm; E = 210 GPa; A = 76.70 cm^2; J_y = 3038.3 cm^4; S_y = 375.5 cm^3; G = 81.1 GPa; n = 0.295 (Poisson's ration)

- 1st variant – After time, our rail-track have weight loss ration of corrosion = 0.013 and E_2 = 190 GPa (using data from [6])
- 2nd variant – After time, our rail-track have weight loss ration of corrosion = 0.019 and E_2 = 185.2 GPa (using data from [6])

Table 1 Calculation results

	non-corroded track	1-st variant	2-nd variant
E [MPa]	210000	210000	210000
E_2 [MPa]	–	190000	185200
a_1	9.994×10^{-5}	10.7232×10^{-5}	11.0732×10^{-5}
a_2	0	0.7594×10^{-6}	1.0710×10^{-6}
s_x [MPa]	20.9871	23.8092	25.0736
% increase	–	13.45	19.47

4 Conclusions

It is tremendously complicated to determine the influence of the corrosion over the rails, so this requires the search for theoretically based modules to calculate the stress and the capability of carrying weight.
The results show considerable influence of the corrosion over the stress and accordingly over the capability of carrying weight and the eventual term of the overall possible usage of the rails. The theoretical module which is suggested by us is characterised by the improvement of the existing methods of calculation. With this we have achieved greater precision and exactitude in the determination of the stress. It is however considerably labour-consuming, so that makes its use in practice not very applicable.
If there appears a connection between the development of the corrosion in time [9] and the change of the geometrical characteristics and the relative mechanical properties – this model can be applied. It can then help to determine precisely the stress, which would unavoidably appear as a result of the corrosion of the rails.

Acknowledgment

The paper is published with the support of the project No BG05M2OP001-2.009-0033 "Promotion of Contemporary Research Through Creation of Scientific and Innovative Environment to Encourage Young Researchers in Technical University – Sofia and The National Railway Infrastructure Company in The Field of Engineering Science and Technology Development" within the Intelligent Growth Science and Education Operational Programme co-funded by the European Structural and Investment Funds of the European Union.
The author would like to thank for the support and assistance on Prof.Dr.Eng. Yavor Mihov, University of Architecture, Civil Engineering and Geodesy, Faculty of Hydraulic Engineering, Department "Technical Mechanics".

References

[1] Tzenov, Tz.: Corrosion of materials, 2006, ISBN 978-954-751-071-5

[2] Brimann, F.: Series Masuremente at the rail for determination of the guide forces (in German), ETR Eisenbahutechnische Rundschau, 1966, 15.5: 155-164.

[3] Timoshenko, S.P., Gere James, M.: Mechanics of materials, 2002, ISBN: 5-9511-0003-8

[4] Shopov, A., Ganev, R.: Survey on many-years influence atmospheres conditions on strain of the reinforced steel Φ6.5 (A-I) for once more using, Proceeding of International Jubilee Scientific Conference "75th Anniversary of UACEG", ISSN 2534-9759 (in press)

[5] Xu, G., et al.: Mechanical properties of steel corrosion products in reinforced concrete, Materials and Structures, 2017, 50.2: 115, doi: 10.1617/s11527-016-0985-3

[6] Gao, D., Zhao, Z.: Experimental study on mechanical properties degradation of TP110TS tube steel in high H2S corrosive environment, Computers Materials and Continua, 2011, 26.2: 157-166.

[7] An, L., et al.: A simple approach to determine mechanical properties of rust layer on steel substrate, Proceeding of the Japan Concrete Institute, 2014, 36.1: 1264-1269.

[8] An, L., et al.: Determination of young's modulus of rust-layer by bending experiment, Proceeding of the Japan Concrete Institute, 2013, 35.1: 1117-1122.

[9] Svintradze, D., Pidaparti, R.: A theoretical model for metal corrosion degradation. International Journal of Corrosion, 2010, doi: 10.1155/2010/279540