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CLIMATE CHANGE AND RAILWAY INFRASTRUCTURE: CHALLENGES AND ADAPTIVE MEASURES

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Abstract

Extreme weather conditions caused by climate change have a negative impact on transportation infrastructure, especially railways. Most common negative impacts of climate change on railways include track buckling, changes in the geometric position of the contact wire, erosion, bridge failures and landslides, which lead to service interruptions, safety hazards and economic losses. This paper analyses the degradation of track superstructure caused by the most common extreme weather conditions in Europe in recent years – high temperatures, heatwaves, floods, storms and extreme winds. It also gives short overview of the methods that could be used during track construction or reconstruction to prevent these damaging effects and highlights the importance of new monitoring methods for track construction using infrared thermography. In addition, a case study of a field measurement on a railway infrastructure in Croatia is presented, where the condition of the track ballast was determined using infrared thermography.

Keywords: climate change, railway infrastructure, track superstructure, infrared thermography

1 Introduction

Model predictions indicate that climate in Europe will change during the 21st century. The mean annual temperature will rise by 1 to 5.5°C and the annual precipitation will increase in the north and decrease in the south. Mean annual wind speeds will also increase in the north and decrease in the Mediterranean regions. Extreme wind speed can increase in western and central Europe and in the North Sea area. Climate changes will also cause the sea level in some areas to rise up to 0.9 m by the end of this century [1, 2]. Climate changes pose a great challenge for the operation and maintenance of the transportation infrastructure [1,3]. According to [4] about 27% of all global road and railway infrastructure is exposed to at least one hazard and operators have recognised the negative impact of climate change on their infrastructure and are aware of the high costs which extreme weather conditions can have on infrastructure. Worldwide, the expected annual maintenance costs due to direct weather-related damage to road and rail infrastructure amount to between 3.1 and 22 billion US dollars, of which around 73% is attributable to surface and river flooding [4].
In winter, strong winds and snowfall can cause snow drifts on the railway infrastructure and disrupt train services. On the other hand, heat waves can cause the rails to buckle, which can lead to traffic disruptions and, in extreme cases, derailment of rail vehicles [5]. Figure 1 shows failures of the system components related to the certain weather phenomena.

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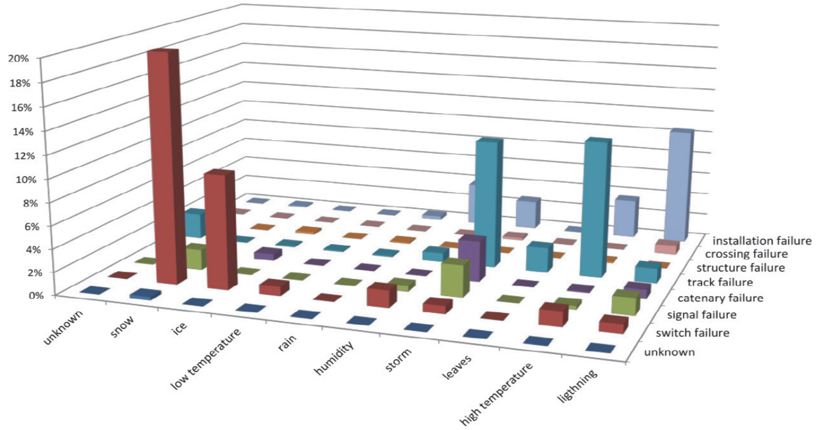

Figure 1 Frequency of the occurrence of a failure model in regard to the weather event [6]

This paper describes the influence of high temperatures, rainfall and flooding, extreme winds, and storms on the track superstructure. As it is not always possible to prevent harmful weather conditions, it is imperative to adapt the railways by implementing various methods of track protection and track monitoring. Chapter 3 analyses monitoring methods of ballast tracks and describes a case study conducted in Zagreb, Croatia using infrared thermography.

2 Impact of climate changes on railway superstructure

2.1 Heatwaves and high temperatures

Heatwaves can cause changes in geometry of rail superstructure, and in extreme cases, cause rails to buckle which can result in traffic disruptions or derailments. The hot and dry conditions can also lead to vegetation and forest fires, which can be triggered by contact between rails and wheels of the vehicle [1]. According to [7], track buckling and other track misalignments were the main cause of rail accidents in 2016, with more than 6 000 incidents in the European Union (EU) in 2018. As a result of the effect of high temperatures on the railway superstructure, compressive forces occur in the rails, as well as due to braking, wheel friction during driving and sticking of the wheels in curves. In the moment when the action of external forces is greater than the lateral resistance of ballasted tracks, buckling of the rails will occur.

In addition to the rails, high temperatures affect the elongation of turnout elements, which are very sensitive to changes in geometry. The paper [8] shows that changes in the geometry of turnouts are one of the leading reasons for derailment during summer months. Influence of high temperatures on catenary systems causes the wires to elongate, which is problematic for maintaining contact between pantograph and the catenary system [9].

2.2 Extreme winds and storms

The impact of strong gusts of wind and storms on the superstructure can be manifested through fallen trees and cuts in power lines [10], leading to the interruption of railway traffic and large costs of rehabilitation. Apart from the fallen trees, the wind often blows debris, branches and leaves from the trackside onto the train tracks. Wet leaves can stick to the rails, thus affecting the friction between the rails and the wheels, causing the trains' stopping distance to elongate. According to [1], winds with the speed more than 32 m/s can cause delays and interruptions of railway traffic due to huge amount of fallen trees, power failures and damages to traffic control devices and structures.

2.3 Rainfall and flooding

Flooding is an extreme weather event that can cause damage to the stability of railway embankments and cuttings, ensuing a negative impact on the railway superstructure, especially on railway ballast bed. In addition, flooding can cause a short circuit in electrical installations, leading to interruptions in the power supply. According to [11], the estimated annual cost of repairing tracks damaged by flooding in the EU is around 581 million euros. Table 2 shows the damage to track caused by different water levels.

Table 1 Damages to railway track caused by different water levels [12]

Water level regarding the top edge of the rail [m]	**Damages to railway track**	**Risk level**
Less than -2,5	-	No risk
-2,5 to -0,45	Subgrade	Low
-0,45 to 0	Part of railway ballast	Middle
0 to 0,5	Railway ballast and smaller parts of subgrade	High
Over 0,5	Subgrade and most of the ballast	Very high

3 Monitoring of ballasted tracks

Despite numerous methods of adapting the track construction to extreme weather conditions, such as increasing the lateral resistance of the track, protecting the track from the wind with wind barriers, installing rock armour on the ballast to prevent the ballast from being washed away during floods, etc., the damaging consequences of extreme weather conditions cannot be completely avoided and regular track control and monitoring must be performed [13]. We can say that climate adaptation for railway networks involves managing traffic administration, encompassing both infrastructure and vehicles, to effectively reduce and manage risks stemming from extreme weather events and the gradual deterioration of infrastructure [3].

Considering the linear nature and area coverage of railway infrastructure, existing methods of track monitoring are time-consuming, expensive, unsafe for the personnel participating and often adjustments to the timetables are necessary. Most of the existing methods are also problematic for use on inaccessible terrain. For this reason, it is necessary to develop additional methods of track monitoring to alleviate some of these shortcomings and allow inspections to be carried out in a shorter time period. Implementing infrared thermography for monitoring of railway superstructure would mitigate some of these shortcomings. This non-intrusive method offers a prompt assessment of possible thermal anomalies indicative of substructure defects, enabling timely maintenance interventions to prevent potential failures and ensuring the integrity of railway infrastructure under diverse environmental conditions.

Case Study: Analysis of railway ballast condition using infrared camera on railway track section in Croatia

To analyse the condition of railway ballast and sleepers, infrared thermographic imaging was used on railway track section on Podsused train station in Zagreb, Croatia. Measurements were conducted using Fluke TiS45 infrared camera from the ground to correlate the obtained temperature values with the condition of railway ballast.

Assumption was that thermal properties of a new railway ballast differ from those of a muddy ballast due to difference in the content of fine particles and fines. Fine particles and fines in muddy ballast lead to water, which causes an increase in water pressure in the pores and reduction in overall strength of ballast bed, leading to decreased travelling safety and comfort, and in extreme cases train derailment.

Four rail track sections for testing were determined by a visual inspection, based on different levels of silting, as shown in Figure 2. Track 2 was visually determined as most favourable which correlates with the fact that it was renovated in 2022, while track 1 was determined as most silted (last renovation was in 1970). Tracks 4 and 6 also show that, while ballast surface is clean, when material is excavated around the sleeper there are different levels of silting.

Figure 2 Analysed rail track sections with different levels of silting

Thermal camera was mounted to a vertical rod at a height of 1.5 m and at an angle of 45°, relative to horizontal, to mitigate harmful effect of reflection [14]. Camera was positioned at 0.5 m from the edge of the sleeper and in line with the centre between two sleepers, 0.3 m from each sleeper (Figure 3). Considering that thermal imaging was carried out point by point, temperatures were obtained on 28 to 30 measurement points for each track. Laboratory testing of granulometric composition was conducted for each of the four tracks. Samples of ballast material were excavated from the centre of the ballast bed and underneath the lower edge of the sleeper due to higher sampling accuracy, i.e. a higher proportion of fine particles and fines. Sampling of the material and granulometric analysis were conducted in accordance with EN 932-1:1996 [15] and EN 933-2:2012 [16], respectively.

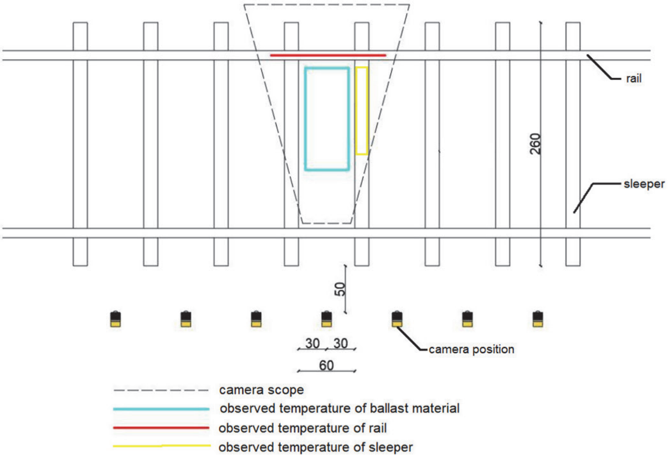

Figure 3 Aerial view of the position of the thermal camera

Obtained information includes average temperatures of rail, ballast material and sleepers derived from thermograms, granulometric composition of ballast, camera angle and distance from rail track as well as most favourable meteorological and weather conditions for testing. Thermographic images were processed in SmartView software, from which minimal, average and maximum temperatures were acquired. Granulometric composition was determined in the laboratory by analysing the ballast samples taken from each track.

Results show a strong correlation between thermograms and granulometric composition reports. Ballast beds with higher percentage of optimal sized grain and a smaller proportion of fine particles and fines achieve higher relative temperatures, than the relative temperatures of the ballast beds with a smaller percentage of optimal sized grain and a higher proportion of fine particles and fines. Table 2 shows results of granulometric composition analysis compared with temperatures obtained from thermograms.

Table 2 Results of granulometric composition analysis in comparison with values derived from thermograms

	Track 2	Track 4	Track 1	Track 6
Mean value of relative temperature of ballast material [°C]	-0.1	-0.6	-2.3	-3.8
Proportion of optimal sized grains (31.5-63 mm) [%]	95.5	59.1	49.9	21.0
Proportion of fine particles (<0.5 mm) [%]	0.1	1.6	3.5	3.2
Proportion of fines (<0.063 mm) [%]	0.2	0.8	2.0	1.8

Results of granulometric reports show that tracks 2 and 4 have higher proportions of optimal sized grain, which correlates with higher relative temperatures, as shown in diagram of relative temperatures for 28 measurement points (Figure 4).

Relative temperature, obtained as difference between average temperature of ballast and rail, is used to reduce temperature variations throughout measurement period. According to [14], temperature of rail can be used as a substitute for the direct measurement of the ambient temperature due to rails' fast adjustment to the environment because of low thermal capacity of steel.

Tracks 1 and 6, which have higher proportions of fine particles and fines, have lower relative temperatures, which confirms initial assumption that thermal properties of new or recently reconstructed ballast bed differ from those of silted ballast bed due to difference in the content of fines particles and fines. Relative temperatures of ballast material for these tracks are shown in Figure 4, for 27 measurement points.

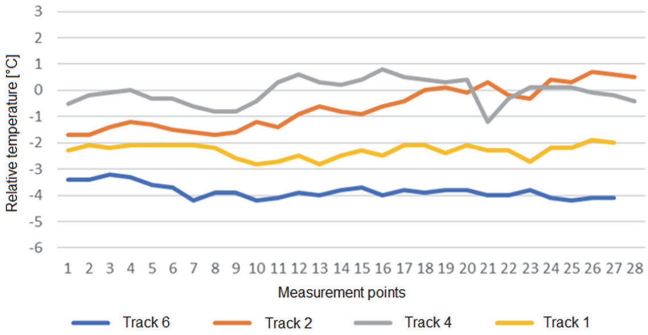

Figure 4 Diagram of relative temperatures of ballast material

4 Conclusion

The impact of climate change on railway infrastructure poses a significant challenge and requires innovative monitoring methods for effective adaptation. The use of infrared thermography is proving to be a promising solution for the non-intrusive detection of climate-related impacts on railway infrastructure. Preliminary research in Podsused, Zagreb, demonstrates the feasibility and effectiveness of this approach and highlights the potential for proactive infrastructure maintenance. However, further research is essential to refine and optimize the implementation of thermography for railway monitoring. Recommendations include further exploration of thermography combined with UAV technology, addressing regulatory and reliability challenges, and investing in advanced analytics and proper operator training to maximize the benefits of infrared thermography for railway infrastructure maintenance and resilience in the face of climate change.

References

[1] Garmabaki, A.H.S., Thaduri, A., Famurewa, S., Kumar, U.: Adapting railway maintenance to climate change, Sustainability, 13 (2021) 24, DOI: 10.3390/su132413856

[2] Rossetti, M.A.: Potential Impacts of Climate Change on Transportation, The Potential Impacts of Climate Change on Transportation, Federal Research Partnership Workshop, pp. 209-221,1-2 October 2002.

[3] Thaduri, A., Garmabaki, A., Kumar, U.: Impact of climate change on railway operation and maintenance in Sweden: A State-of-the-art review, Maintenance, Reliability and Condition Monitoring, 1 (2021) 2, pp. 52–70, DOI: 10.21595/mrcm.2021.22136

[4] Koks, E.E., et al.: A global multi-hazard risk analysis of road and railway infrastructure assets, Nat Commun, 10 (2019) 1, DOI: 10.1038/s41467-019-10442-3

[5] Wang, T., Qu, Z., Yang, Z., Dimitriu, D., Clarke, G., Bowden, D.: Impacts of climate change on rail systems: A new climate risk analysis model, Safety and Reliability – Safe Societies in a Changing World, pp. 2771–2779, 2018, DOI: 10.1201/9781351174664-348

[6] Stipanovic, I., Hartmann, A., Dewulf, G., ter Maat, H.: Risk Assessment Of Climate Change Impacts On Railway, Engineering Project Organization Conference Devil's Thumb Ranch, Colorado, 9-11 July 2013.

[7] Sanchis, I.V., Franco, R.I., Zuriaga, P.S., Fernández, P.M.: Risk of increasing temperature due to climate change on operation of the Spanish rail network, Transportation Research Procedia, 45 (2020), pp. 5–12, DOI: 10.1016/j.trpro.2020.02.056

[8] Dindar, S., Kaewunruen, S., An, M., Osman, M.H.: Natural Hazard Risks on Railway Turnout Systems, Procedia Engineering, pp. 1254–1259, DOI: 10.1016/j.proeng.2016.08.561

[9] Nilsson, F., et al.: Modelling anti-icing of railway overhead catenary wires by resistive heating, International Journal of Heat and Mass Transfer, 143 (2019), DOI: 10.1016/j.ijheatmasstransfer.2019.118505.

[10] Tahvili, N.: Winterization of Railways Issues and Effects, Faculty of Social Science and Technology Management, Norwegian University of Science and Technology, doctoral thesis, 2016.

[11] Bubeck, P., Dillenardt, L., Alfieri, L., Feyen, L., Thieken, A.H., Kellermann, P.: Global warming to increase flood risk on European railways, Clim Change, 155 (2019) 1, pp. 19–36, DOI: 10.1007/s10584-019-02434-5

[12] Sulejmanović, S., et al.: Flood Risk Analysis on the Rail Network at Federation of Bosnia and Herzegovina, International Symposium on Innovative and Interdisciplinary Applications of Advanced Technologies, pp. 196–208, 2022.

[13] Zarembski, A.M.: Survey of Techniques and Approaches for Increasing the Lateral Resistance of Wood Tie Track, Department of Civil and Environmental Engineering, University of Delaware, Newark, Delaware, 2016.

[14] Hosseini, S.M., Tan, T., Ahmadian, M.: Forward-looking infrared radiometry (FLIR) application for detecting ballast fouling, Joint Rail Conference, St. Louis, Missouri, 20–22 April 2020, DOI: 10.1115/JRC2020-8032

[15] EN 932-1:1996: Tests for general properties of aggregates - Part 1: Methods for sampling

[16] EN 933-1:2012: Tests for geometrical properties of aggregates - Part 1: Determination of particle size distribution - Sieving method