Editorial

Smart condition assessment of railway infrastructure

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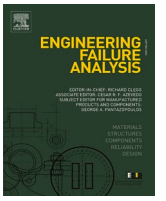

Editorial: Smart condition assessment of railway infrastructure

A B S T R A C T

This editorial is referred to the Special Issue (SI) "Smart Condition Assessment of Railway Infrastructure" which aims to bring together the latest research studies, findings, and achievements regarding the smart condition assessment of railway infrastructure to prevent critical failure mechanisms. This SI counted with 20 high quality technical and scientific contributions involving 112 authors of 5 countries.

1. Introduction

In recent years, important investments have been made in the construction of new railway lines, as well as in the rehabilitation and upgrading of existing lines. Many of these lines include a significant amount of critical infrastructure whose operational and safety conditions must be preserved by the infrastructure managers throughout the entire life cycle.

Recent scientific and technological advancements have enabled a more efficient structural condition assessment of railway infrastructure, mainly through the implementation of intelligent strategies (Fig. 1). These strategies can help investigating the cause of failure of critical engineering components, structures, or systems, as well as identifying preventive actions to avoid future failures [1–6].

This Special Issue is focused on the smart condition assessment of the railway infrastructure envisaging a better understanding and prevention of the main critical failure mechanisms associated with railway assets. Furthermore, a special highlight is given to the investigation focused on the automatic, smart, and real-time identification of failure mechanisms, its causes and mitigation measures to avoid future failures.

Therefore, authors submitted the latest research studies, findings and achievements involving emerging technologies and methodologies on structural integrity and condition assessment of railway infrastructures. These works include theoretical, experimental, and computational investigations, or a combination of these. All the accepted works will give a relevant contribute for the real implementation of these emerging technologies and methodologies in the railway industry.

2. An overview of published papers

A total of 20 papers have been accepted for publication in the context of the Special Issue after a comprehensive and strict review process, and their respective contributions are detailed as follows:

1- R. Wang, J. Leander (2023) - "*Risk-based decision-making for system-level fatigue assessment of bridges*", 153:107533. https://doi.org/10.1016/j.engfailanal.2023.107533

2- J. Morais, E. Fortunato, D. Ribeiro, R. Calçada, J. Mendes (2023) - "*Railway track support condition assessment - Methodology validation using numerical simulations*", 152:107483. https://doi.org/10.1016/j.engfailanal.2023.107483

3- H. Li, L. Li, Z. Li (2023) - "*Research on the effect of rail cant on the dynamic performance and wear characteristics of subway vehicles*", 152:107478. https://doi.org/10.1016/j.engfailanal.2023.107478

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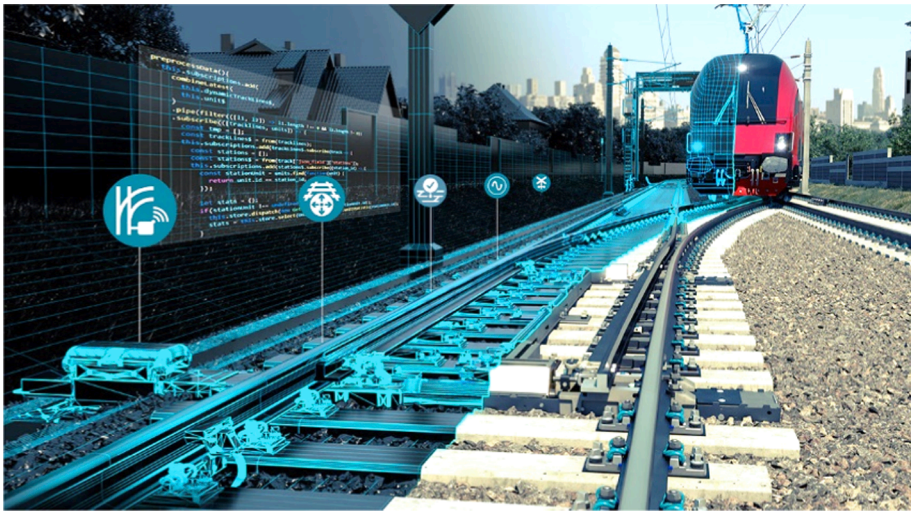

Fig. 1. Intelligent monitoring system on trackside [7].

4- X. Cui, S. Peng, L. Yu, J. Xu, H. Ding, Y. Qi, Y. Hongjuan (2023) - "*Fracture mechanism and control method of elastic strip of Cologne-egg fastener in the high-prevalence section of rail corrugation*", 152:107463. https://doi.org/10.1016/j.engfailanal.2023.107463

5- B. Torres, P. Poveda, S. Ivorra, L. Estevan (2023) - "*Long-term static and dynamic monitoring to failure scenarios assessment in steel truss railway bridges: A case study*", 152:107435. https://doi.org/10.1016/j.engfailanal.2023.107435

6- A. Lourenço, C. Ferraz, D. Ribeiro, A. Mosleh, P. Montenegro, C. Vale, A. Meixedo, G. Marreiros (2023) - "*Adaptive time series representation for out-of-round railway wheels fault diagnosis in wayside monitoring*", 152:107433. https://doi.org/10.1016/j.engfailanal.2023.107433

7- S. Wang, L. Zhang, Y. Qian, Y. Zhou (2023) - "*Portray rail head surface crack 3D contour through image analysis and morphology reconstruction*", 151:107374. https://doi.org/10.1016/j.engfailanal.2023.107374

8- Q. Ma, K. Wang, X. Wang, Z. Zheng, Z. Li, J. Fang, K. Xiang, J. Xu, R. Chen, P. Wang (2023) - "*Numerical and experimental investigation of longitudinal rail creep at turnouts on steep ramps under repeated loads considering realistic braking loads of vehicles*", 151:107380. https://doi.org/10.1016/j.engfailanal.2023.107380

9- X. Kang, G. Chen, X. Chen, C. Deng, Y. Ma, Y. Zhao, S. Lu (2023) - "*Analysis of the generation mechanism and evolution of the wheel high-order polygonal wear of subway trains*", 151:107375. https://doi.org/10.1016/j.engfailanal.2023.107375

10- Y. Peng, M. Deng, Y. Yu, Z. Hu, K. Wang, X. Wang, S. Yi, G. Deng (2023) - "*Analysis of moose motion trajectory after bullet train-moose collisions*", 151:107373. https://doi.org/10.1016/j.engfailanal.2023.107373

11- X. Gao, Q. Feng, Z. Wang, L. Liu, A. Wang (2023) - "*Study on dynamic characteristics and wide temperature range modification of elastic pad of high-speed railway fastener*", 151:107376. https://doi.org/10.1016/j.engfailanal.2023.107376

12- Y. Tang, G. Gao, K. Liu, K. Chen, Y. Xie, D. Xin, S. Zhou, G. Wu (2023) - "*Electric field distribution and performance optimization of high-speed train cable terminal with internal defects*", 151:107360. https://doi.org/10.1016/j.engfailanal.2023.107360

13- L. Tan, X. Hu, T. Tang, D. Yuan (2023) - "*A lightweight metro tunnel water leakage identification algorithm via machine vision*", 150:107327. https://doi.org/10.1016/j.engfailanal.2023.107327

14- S. Sun, Q. Xu (2023) - "*Experimental study on the interface fatigue between track slab and self-compacting concrete for CRTS III slab track*", 150:107302. https://doi.org/10.1016/j.engfailanal.2023.107302

15- M. Khosravi, A. Ahmadi, A. Nissen (2023) - "*A Multi-objective approach for position alignment of track geometry measurements*", 149:107260. https://doi.org/10.1016/j.engfailanal.2023.107260

16- J. Ren, Q. Zhang, Y. Zhang, K. Wei, K. Zhang, W. Ye, Y. Zhang (2023) - "*Evaluation of slab track quality indices based on entropy weight-fuzzy analytic hierarchy process*", 149:107244. https://doi.org/10.1016/j.engfailanal.2023.107244

17- G. Zhang, C. Liu, S. Wu, T. Cong, Y. Wu, B. Zhang, R. Ren (2023) - "*A study on the rolling contact fatigue mechanism of ZC-L cast wheel steel*", 148:107221. https://doi.org/10.1016/j.engfailanal.2023.107221

18- X. Xiang, H. Zhang, F. Zhang, Z. Yang, Q. Xu, Y. Zhang (2023) - "*Failure analysis of the conductive slide support rod of section insulator applied in urban rail transport system*", 148:107217. https://doi.org/10.1016/j.engfailanal.2023.107217

19- Z. Lao, D. He, Z. Wei, H. Shang, Z. Jin, J. Miao, C. Ren (2023) - "*Intelligent fault diagnosis for rail transit switch machine based on adaptive feature selection and improved LightGBM*", 148:107219. https://doi.org/10.1016/j.engfailanal.2023.107219

20- X Liu, C. Liu, W. Wu, J. Liu, S. Sun, Y. Wei (2023) - "Transient dynamics of a full wheel rail set passing a weld irregularity at high speed", 148:107203. https://doi.org/10.1016/j.engfailanal.2023.107203

The contributions span diverse geographical regions, encompassing specific country cases such as China, Portugal, Spain, Sweden, and USA.

Published papers covered the following topics: structural integrity (2, 9, 10, 14, 20), structural condition assessment (1, 2, 4, 5, 8, 10, 13, 15, 16, 20), degradation mechanisms (3, 4, 7, 8, 9, 12, 14, 16, 17, 18, 19), intelligent fault prognosis (6), structural health monitoring (3, 5, 8), new sensors and technologies for damage identification (5, 8), non-destructive testing (10, 17), computer vision (13), automated damage identification (6, 17), remote inspection (13), artificial intelligence (6, 13), disaster risk analysis (1, 10), and case studies of failures in railway infrastructures (1, 5, 13, 14, 15, 16, 18, 19).

Contribution 1 presents a study on decision-making for existing fatigue-sensitive bridges using both reliability-based and risk-based approaches. As the basis of the study, a probabilistic fatigue assessment is used to evaluate possible action alternatives to extend the service life of an existing railway bridge. The decision scenarios are established by considering the associated consequences and potential costs. The results shows that system setups directly impact on the system reliability and further lead to different optimal decisions. Additionally, when the probability of failure due to fatigue is relatively low, local fatigue will not significantly influence the failure of the bridge or the optimal decision.

Contribution 2 presents a novel methodology to evaluate railway track support conditions. This methodology is based on modal analysis of the multi-element system composed by the railway infrastructure and an instrumented railway vehicle. The proposed methodology is focused on the condition assessment of the entire extension of a railway infrastructure subgrade. In addition, it can assess the evolution of track support conditions over time by comparing different passages over the same railway stretch. An important aspect of this methodology that still lacks validation is the topic of characterizing track support conditions of a railway infrastructure through its natural frequencies. Preliminary numerical simulations tests using the simulation software Simpack® support the selected theoretical model and the overall validity of the methodology.

Contribution 3 employs a combined approach of field measurements and numerical simulations to investigate the influence of deviations from the standard values of rail cants on the vehicle's straight-line operating performance and wheel wear. Additionally, it analyzes the difference in the effects of asymmetric rail cant on the inner and outer wheel's curve negotiation performance and wear characteristics. The research demonstrates that for straight track sections, rail cants ranging from 1/30 to 1/10 significantly reduce the critical speed of the wheel-rail wear profile, thereby affecting the operational stability of the vehicles. For curved track sections, when the inner rail cant is within the range of 1/60 to 1/50, the derailment coefficient and wheel-rail lateral forces of the outer wheel increase significantly, and they are directly proportional to the degree of wheel-rail wear. When the inner rail cant is 1/30, the wheel-rail profiles at different wear stages often exhibit optimal curve negotiation performance.

Contribution 4 focuses on the fracture mechanism and control method of the Cologne-egg fastener elastic strip in the high-prevalence section of rail corrugation. Firstly, the numerical simulation model of wheel-rail-fastener system considering the key components of Cologne-egg fastener is completely constructed. Then, the fracture mechanism of Cologne-egg fastener is explored by comprehensively considering the resonance response and fatigue failure of the fastener elastic strip. Finally, the corresponding control methods are proposed by the passive control of rail grinding and active adjustment of fastener structure. Analysis results show that the intensified wheel-rail friction coupling vibration in the corrugation zone leads to the resonance response of the Cologne-egg fastener elastic strip, which intensifies the vibration response of elastic strip. Then, the aggravation of vibration response of the Cologne-egg fastener elastic strip leads the fatigue of the elastic strip, and the outer elastic strip is easier to fracture than the inner elastic strip on the low rail of small-radius curve.

Contribution 5 describes a case study of failure scenarios assessment in a steel truss-type railway bridge after extensive long-term monitoring using vertical deflections and modal frequencies. The structure has both an isostatic and a hyperstatic configuration and was assessed by means of a combination of long-term monitoring results, and a FE analysis to simulate several failure scenarios. A sensitivity study of the different failure scenarios was carried out, identifying those that can be detected. The results are used to define practical recommendations for failure detection by measuring vertical deflections and modal frequencies.

Contribution 6 presents a novel approach for wheel out-of-roundness diagnosis (i.e., flats, wear treads and polygonization) involving the: i) detection of aberrant train behavior, ii) isolation of specific defective wheels, and iii) identification of the severity. For this, the methodology automatically segments a strain gauge signal, capturing the complex nature and temporal dependence of vibration patterns. This segmentation allows the extraction of localized accelerometer features in both the time and frequency domain, as well as implicit axle count and labelling of each wheel passage. Moreover, a single-value damage indicator based on anomaly detection algorithms was proposed. To validate the effectiveness of the proposed methodology, experiments on a set 3D numerical train-track dynamic interaction simulations are performed for different wheel profiles, track irregularities, train speeds, sensor placement and noise, associated to other environmental/operational variations. This demonstrates the potential of artificial intelligence for real-time assessment of wheels without interfering with normal service conditions, suggesting the possibility of automated fault diagnosis.

Contribution 7 aims to capture the true 3D shape of fatigue cracks during initiation and propagation. New mathematical and physical models, based on reconstructed 3D cracks, are proposed to predict rail crack propagation at various service stages. The analysis reveals that the crack propagation path in the 2D lateral rail section approximates a quadratic parabola or circular curve, and the 3D crack morphology is like a partial spherical surface. The reconstruction model proposed can predict internal crack propagation on the rail head surface, assisting in track inspection, maintenance, and repair.

Contribution 8 aims to study the longitudinal rail creep at turnouts on steep ramps subjected to both temperature loads and vehicle braking loads, which may lead to a turnout service failure and threatening vehicle operation safety. Experiments were conducted to investigate the longitudinal resistance characteristics of fasteners under repeated loading, and based on the experiment results, an MBS-FE simulation model was established for the longitudinal rail creep at turnouts on steep ramps, with real vehicle braking loads and fastener resistance degradation taken into consideration in the model. A full-scale experiment was then conducted on the longitudinal rail creep at turnouts on steep ramps under repeated loading conditions to verify the results of the simulation. A

comprehensive and in-depth study of the longitudinal rail creep at turnouts on steep ramps impacted by repeated loading was conducted through the combination of theoretical analysis and experiment. The results show that the longitudinal resistance of fasteners displays typical nonlinear characteristics and degrades under repeated loading. Also, the simulation results were found to be very similar to the full-scale experiment results, verifying the accuracy of the proposed analytical model.

Contribution 9 aims to study the generation cause of initial high-order polygonization of subway wheels and its evolution. The friction-induced self-excited oscillation caused by the saturated wheel-rail creep force was used as the frequency-fixing mechanism of the wheel OOR wear, and the wheel polygonization induced via this oscillation was evaluated by FE simulation. Furthermore, the influence of rail corrugation on the development of wheel OOR wear was analyzed, and it is found that, when the vehicle negotiates a small-radius curve track, an unstable oscillation of 87 Hz induced by the saturated creep force can lead to wheel 12th/13th-order OOR wear. During vehicle operation, the vibrations caused by the wheel 12th/13th-order polygonization can excite the eigenmodes of the wheelset, leading to an increased wear intensity. In addition, wheel 12th-order polygonal wear interacts with the rail corrugation of the same wear wavelength but different phases, which can cause wheel 10th/11th- and 13th/17th-order polygonization.

Contribution 10 aims at investigating the train crash safety and moose motion trajectory in train-moose collisions for different moose crossing scenarios using the FE method. Material biomechanics tests were conducted to obtain the mechanical property parameters of moose. Drop hammer impact tests were performed to validate the constitutive models of different moose segments. The numerical impact simulations of moose crossing the rail at different collision positions were established in LS-DYNA. The results showed that the impact force depends on the contact area between the train and the moose, where a larger contact area corresponded to a larger impact force. In addition, the moose would be pushed away by the V-shaped locomotive and would not cause a derailment, and the height of the moose thrown into the air cannot reach the height of the pantograph, which would prevent damage to the pantograph of a bullet train.

Contribution 11 aims to test and conclude the service performance and online track modal recognition of the W300-1 fastener system. A comprehensive test system is used to obtain the dynamic characteristics of fasteners with the preload under the temperature-dependent (−70 °C to 50 °C) and frequency-dependent (10–1250 Hz) coupling conditions. The results indicate that the frequency-dependent characteristics of elastic pad enable the first-order modal frequency to shift toward a higher frequency, accompanied by the amplitude increase. The temperature-dependent characteristics of elastic pad make the medium- and high-frequency decay rate of rail wider but smaller. To enhance the fastener system performance, the polymer materials of elastic pad are modified and optimized from two perspectives of polyol type and crosslinking agent type. Based on the standard requirements of Q/CR7-2014, the dynamic performances of polymer materials can meet the requirements of safety and stability of high-speed railway.

Contribution 12 studies the electric field intensity distribution of high-voltage cable terminal of high-speed electric multiple units (EMU) with internal defects, such as, air gaps, moisture, semiconductors, and carbons. The results show that the defects are closer to the multi-layer combination area among main insulation layer, stress tube layer and outer semiconducting layer of the cable terminal, and therefore, the electric field distortion of multi-layer combination area become greater. With the increasing of defect size, the electric field intensity also gradually increases. However, the inner defect location and size have less effect on the electric field intensity along the cable terminal umbrella skirt. Finally, it was found that both nonlinear materials and high dielectric materials can effectively optimize the electric field intensity of cable terminal and improve the electric field distortion.

Contribution 13 aims to propose a method for water leakage segmentation task on metro tunnels. The huge image collected by sensing vehicle is too large to be processed directly, so an image cropping and stitching algorithm was implemented. Also, the optimization of the inference speed required the design of a Lightweight Segmentation Network (LSNet), particularly the Shuffle Net v2 as encoder, especially dedicated to accelerating the water leakage segmentation on the metro shield tunnel. Also, a decoder was developed using the skip-connection structure to maintain the algorithm accuracy. Experiments based on a real dataset show the superiority of the model proposed which can process > 120 frames per second.

Contribution 14 aims performing static and fatigue splitting tensile tests, regarding the interface failure mechanism between the precast track slab and the cast-in-place self-compacting concrete, in a CRTS III slab track system. Most of the interface failures were mortar failures and mortar-aggregate bond failures, and only a few were aggregate failures. Regarding the evolution law of the interface strain, three growth stages were identified (rapid, stable, and unstable) and the corresponding S-N curve was obtained. Finally, based on the residual strain, an interface fatigue damage model was established to reveal the evolution law of damage variables with fatigue life ratio under different stress levels.

Contribution 15 aims developing a multi-objective approach for reducing the positional errors in track geometry measurements based on two alignment methods – recursive segment-wise peak alignment (RSPA) and modified correlation optimised warping (MCOW). Furthermore, a novel rule-based approach was introduced to avoid data loss while aligning the datasets of the measurements of linear assets. A case study was conducted to implement and assess the performance of these methods in reducing the positional errors in track geometry measurements. The results revealed that the rule-based method preserves all the single defects present in the datasets. Furthermore, RSPA outperforms MCOW when aligning peaks, whereas MCOW is more efficient when all the data points in the datasets have equal priority.

Contribution 16 aims to guide the maintenance and repair of ballastless track quality by determining a set of comprehensive evaluation indices. Considering the CRTS III slab track system as example, two typical types of damage were considered, namely, cracking and interlayer debonding. Entropy weight method-fuzzy analytic hierarchy process (EWM-FAHP), cracking interspace volume (CIV) and debonding interspace volume (DIV) indexes and subsequent weights were proposed to measure the damage degree. In addition, a model containing cracking and debonding was established using the ABAQUS finite element software, and these weights were modified based on the models' calculated results. Posteriorly, the quality condition index (QCI) was determined to assess the quality state of the slab track under real-scenarios.

Contribution 17 analysed the rolling contact fatigue (RCF) failure mechanism of ZC-L cast steel wheels by using optical microscope (OM), scanning electron microscope (SEM) and transmission electron microscope (TEM). The results show that obvious fatigue flaking is formed on the macroscopic surface of the wheel tread after RCF failure. The RCF cracks are formed at the maximum shear stress region of the sun-surface of the wheel (1–5 mm below the tread). There are a lot of subsurface white etching microstructure (WEM) and obvious casting defects in the subsurface of the wheel tread. The RCF cracks are mainly formed at the interface between the subsurface WEM and the matrix and at the edge of the casting defects. When the plastic deformation reaches the plastic limit, the RCF cracks are formed at the edge of the inclusions due to ratchet failure.

Contribution 18 aims to study the failure of a support rod of conductive slide of a section insulator installed on the pantograph of an urban rail system. Multiple failure causes were analyzed using a combination methods of chemical composition analysis, mechanical property test, metallographic examination, macro morphology and microstructure observation. The failure mechanism of the support rod is proved to be high cycle fatigue fracture. The main fatigue crack origin locates at the right-angle edge of the arc-shaped transition region of the support rod where stress concentration can be generated easily. In addition, arc discharge-induced cracks were observed on the local burned surface of the support rod, which significantly contribute to the fatigue crack initiation. Finally, the alternating load mainly results from the change of train operation direction at the turning position and this change further leads to the direction change of the contact force between pantograph and insulator section. Besides, the impact, vibration and unsmooth contact caused by pantograph also contribute to the alternating load.

Contribution 19 proposes a fault diagnosis method based on improved LightGBM to detect electrical anomalies in a turnout switch machine. Time domain features and multi-scale permutation entropy are extracted to capture the weak fault. Moreover, an adaptive feature selection (AFS) method is presented to reduce redundant features. Especially an improved Focal Loss (IFL) function is established, which improves the ability to distinguish samples of similar features in a multi-classification model. The three-phase action current from the switch machine is used to testify to the proposed method and compare it with other methods. The experimental results show that the diagnosis accuracies of the proposed method in the normal-reverse and reverse-normal conversion process reach 98.5 % and 96.1 %, respectively, which is well-suitable for practical application.

Contribution 20 aims evaluating the operation status of a high–speed train passing over a defective rail weld based on the monitoring of axle box accelerations. The authors propose a FE model for studying the dynamic response of a full wheelset passing weld irregularities at high speed. Simulations provide detailed dynamic information during the pass, such as the peak of the contact force and the history of acceleration. With these simulation results, a standard safety limit for the running speed is proposed, which is a running speed boundary as a function of defect size. Additionally, rail weld defect grinding standards should depend on the running speeds.

3. Final remarks

The Guest Editors are satisfied with the conclusive outcomes of the published papers in this special issue, anticipating their utility for researchers, engineers, designers, and other professionals engaged in diverse thematic aspects of smart condition assessment of railway infrastructure. The Guest Editors extend their appreciation to all authors and reviewers for their crucial contributions and for the dissemination of scientific findings. Lastly, gratitude is extended to the Editor-in-Chief of the Engineering Failure Analysis journal, Prof. Cesar Azevedo, for the patience, support, and exceptional contributions.

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