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Vulnerability Of Railway Switches and Crossings Exposed to Flooding Conditions

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Abstract. Turnouts are a part of modern railway tracks to divert railway traffic from one route to another route. Their complex geometry and structure impose significant dynamic track loads. Particularly, common crossings laid on ballasted tracks are well-known among the infrastructure managers for their drawbacks. Numerous studies have been devoted to analyze a railway turnout with a common crossing. Nevertheless, almost all of them considers that turnouts are working in a dry environment. In reality, railway tracks are exposed to extreme conditions such as flooding, which could damage the power supply, signaling systems, rolling stocks and the infrastructure. The so-called phenomenon 'washed out' or 'washed away' ballast affects directly the dynamic behavior of rolling stock and can cause derailments with fatalities. In 2018, for instance, 25 people were killed in an accident in Turkey as a result of 'washed away ballast'. Few studies analyze unprecedented events in railway tracks in terms of vehicle-track interaction. However, no studies on turnouts was encountered in the literature. Hence, it is a significant contribution to analyze a railway turnout in case flooding occurs. In this study, the beam oriented finite element model, validated previously, is manipulated to analyze the dynamic behavior of a turnout under dry and wet conditions as well as washed away ballast scenarios. The outcomes of the study show that considering the effects of flooding on dynamic forces during operation and design phases could be a key to prevent undesired events.

Keywords: Turnout, railway, flooding, dynamic, finite element method analysis.

1 Introduction

Railways is a safe, secure and rapid transportation mode to convey a large amount of cargo and passengers. The technology behind it has been evolving over the centuries and has no boundaries to reach [1-6]. However, a large portion of the current network is established on ballasted track technology, relatively old technology in which support structure is a ballast-bed that is composed of crushed rocks. The ballasted tracks are inexpensive to construct and have superior properties in terms of noise and vibration mitigation [7]. Furthermore, their porous structure exhibit natural drainage. The problem in ballasted tracks is resilience or insufficiency to provide long-term track stability due to the structure of ballast bed that is highly susceptible to dynamic forces and environmental factors, causing uneven track stiffness and requiring frequent maintenance to restore even track stiffness. Furthermore, providing an evenly distributed track stiffness becomes more challenging at transition points on the track, such as turnouts owing to their asymmetrical and stiff structure that require special maintenance technology.

Turnouts are imperative for railway tracks as they enable diversions of traffic flow from one track to another track. Their asymmetrical structure and complex geometry induce high-frequency impact forces and cause asymmetrical loading conditions, which frequently leads to ballast deterioration and rail damages [8]. Numerous studies have been conducted to analyze and develop a better understanding of the behavior of railway turnouts[8-23]. Nevertheless, most of the studies consider an ideal mid-temperature dry weather condition and neglect the extreme events. Neglecting a few recent studies [24-31], a similar approach is also valid for normal track sections. The reason might be the low frequency of occurrence and the general tendency to stop any rail operations under extreme events [32]. Such an operation contains large uncertainties in terms of operational status and could be very dangerous and fatal. Nonetheless, in some cases, the extreme events are inevitable owing to their unforeseen nature. In 2018, it was reported that a deadly accident in Turkey was due to washed away ballast after an unexpected sudden downpour of rain [33]. Hence, it is crucial to investigate such unprecedented events such as flooding to prevent financial and more importantly, human losses. Despite several studies on railway tracks exposed to flooding, to the authors' knowledge, no study has been encountered in the literature, which assesses the topic in terms of the dynamic behavior of railway tracks as well as turnouts. Consequently, this paper is the first to present the outcomes of the analysis on the dynamic behavior of a turnout system that is exposed to different flooding conditions.

A validated finite element model that was used previously to analyze turnout behavior under dry conditions [34] is modified to represent flood conditions. Two different flood scenarios are tested in the simulation environment. In the first scenario, the relative surface water level is considered, where it is assumed that the porous structure of ballast allows water flow and therefore, there is no washed away ballast. In the second scenario, the assumption is that the ballast bed lose its draining ability and become impermeable structure. Then, the water flow occurs from the weakest point on the ballast bed where water flow is strong enough to drag the ballast particles, leading to the loss of structural integrity. In that case, several bearers have no ground support.

2 Numerical Model

The finite element model in [34] is based on a 48m standard turnout with 1:9 crossing angle, including a small section of normal track. The model uses an equivalent profile for rails to downgrade the complexity of 3D model due to computational limitations. A descriptive figure is presented in Fig. 2.

Fig. 1. A flooded turnout. The picture courtesy of East Midlands Railways.

The model is a composition of the beam and spring-dashboard elements. 77 bearers ranging from 2.4m to 4.7m length are modelled with an average spacing of 0.71m. Fastening systems are simplified as a rubber rail pad and implemented into the model as spring elements. Additionally, damping properties of rail pads are neglected due to the insignificant contribution of pad stiffness into total track damping in comparison to ballast bed. A common concept of 'beam on an elastic foundation' is adopted in the model. Therefore, the ballast bed is represented by spring-dashboard couples. The number of the spring elements is adjusted against the length of the bearers. The ground below the elastic foundation is assumed rigid to be able to define boundary conditions. Boundary conditions allow components to move in their vertical planes. Material properties are inherited from the previous model with an exemption for ballast properties. The ballast properties have been selected with reference to [24], where the effects of different water levels are investigated. Selected water levels and ballast properties are presented in Table 1 as well as other fundamental parameters. For the second scenario, in the case of washed away ballast, the spring elements representing ballast bed was removed for two critical sections (i.e. switch and crossing panels).

The vehicle in the model, consisting of a bogie and two wheelsets, is represented by rigid bodies and springs. The geometry of the car body is neglected owing to the negligible influence on dynamic forces but the weight of the car body is distributed over the bogie. The mass per wheel is 10 tons. The boundary conditions for the vehicle enable longitudinal and vertical movements as well as pitch and roll motion. The travel direction of the vehicle is the facing direction on through route of the turnout and travelling speed is 25 kph. The vehicle speed is selected based on the experience of the second author. Last but not least, the contact between track and vehicle is defined by Hertzian contact theory in which the contact forces are calculated based on the virtual penetration and contact stiffness in FEM environment.

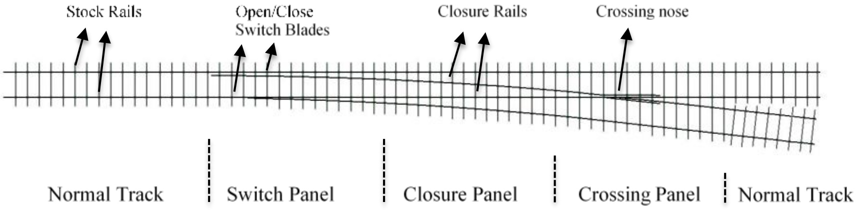

Fig. 2. The used layout of a standard turnout

The solver settings are also obtained from the previous model, where an explicit time integration, well-known for its stability, used to solve equations of motions. Furthermore, preloading is applied to avoid unrealistic vibrations due to gravitational forces. The model has sufficient detailing to obtain accurate results with high resolution in an acceptable calculation time. The original model was validated by field measurements. Here, it is assumed that the validity of the model will not change with the manipulation of the ballast bed properties. This assumption has been done due to lack of field measurements that can be used as a reference point.

Table 1. Dynamic material properties used in the numerical model.

Element	No. Elements	Properties	Value
Rail	1980	ρ^1	7800
		E^2	210
		PR^3	0.3
Bearer	3070	ρ^1	2500
		E^2	38
		PR^3	0.2
Rail Pad	245	k^4	1300
Ballast (0%, 29%, 57%, 100%, 114%)	5900	k^4	14.6, 13.7, 13.4, 11.3 ,6.5
		c^5	1.16, 1.77, 1.82, 2.37, 3.3
Primary Suspension	8	k^4	1.15
		c^5	2.5

1 Density (kg/m3). 2 Modulus of elasticity (GPa). 3 Poisson Ratio. 4 Stiffness (MN/m) 5 Damping coefficient (kNs/m).

3 Results and Discussions

Several track parameters are taken into account to assess the performance of a railway track whether a corrective action is necessary or not. These parameters are measured by determining the position of rails. One should bear in mind that the rails could be subjected to a vehicle loading or no loading. Hence, two different measurement concepts are applied in practice. In this study, the concept of measurements under vehicle loadings is assumed to calculate the track parameters. Indeed, only one track parameter, cross-level, is considered due to the aim of the study and boundary conditions applied in the simulation. The basic definition of the cross-level is the height difference between two rails, which must be kept in certain limits. The limits could vary among the countries as they are decided by the experience of the Infrastructure Managers. Here, the maintenance manual [35] is followed to evaluate the degree of the cross-level. In the manual, it is recommended to take measurements at two different intervals to identify short and long twist defects. The twist value is obtained by subtraction of adjacent measurement points, which should be below the maintenance threshold values in the manual. The threshold value of short twists at 25 kph is between 17-18 mm whereas it is 50-55 mm for long twists. Above threshold values, the maintenance is compulsory. It is noteworthy that there are a few more threshold values above the maintenance thresholds which is applied to determine maintenance priority. The occurrence of long twist is neglected at this point, considering the length of turnout and its rigid structure. Besides, there could be discrepancies in other practices such that only one specific interval, 3m, is used to measure cross-level [36]. Thus, the cross-level values are obtained in the simulations at every 2m, in parallel to the manual, to detect short twist defects. However, it should be emphasized that the thresholds defined in [36] are referenced while discussing the results. This is because the thresholds are not only expressed as millimetric values but also as gradient values. For instance, twists with a gradient between 1 in 127 and 1 in 200 must be repaired in 10 days following the detection. Finally yet importantly, the right rail that is aligned with the crossing nose is selected as a reference rail. If the cross-level have a positive value, it means that the left rail is at a higher position from the ground in comparison to the right rail.

3.1 The Effect of Surface Water Level on Cross-Level at Turnouts

Surface water levels could show variations in different flood scenarios. As indicated in [24], the level of surface water affects the stiffness and damping properties of ballast structure that have an impact on the dynamic behavior of vehicle and track system. Since the available information on ballast structure under flood condition is limited, similar idea applied in [24] is adopted in this study. Here, it is assumed that the ballast structure is exposed to four different surface water levels. The level representation is normalized where water level that covers all structure is considered as %100 flooding. Similarly, the reference case, the dry condition, is indicated as 0% flooding.

The results of different surface water levels are presented in Fig. 2. As can be seen from the figure, the level of surface water is decisive on the magnitude of cross-level. The higher water level means the higher cross-level. The discrepancy seems to be insignificant from 0 to % 100 flooding, whereas 10% above the reference point doubles the cross-level value. The figure also present the asymmetrical stiffness distribution along the turnout due to its geometry. The turnout structure generally acts stiffer at sections under the rail on the crossing side (Fig. 2 top), which seems to lead to negative cross level. Similarly, track stiffness increase towards the longest bearer and the upward trend continues in the direction of the longest bearer. The bearer with no.20, laid at switch panel, has a similar length to a standard bearer whereas the bearer with no.60 is far longer and provide higher track stiffness. Another evidence of the effect of high stiffness on the cross-level is the sudden decrease in the magnitude of the cross-level after no.60 bearer, which results from the transition between turnout structure and normal track section. Lastly, it seems that the cross-level values are in the range of permissible limits and the turnouts could maintain their functions under flooding conditions at low speeds if their structural integrity is protected.

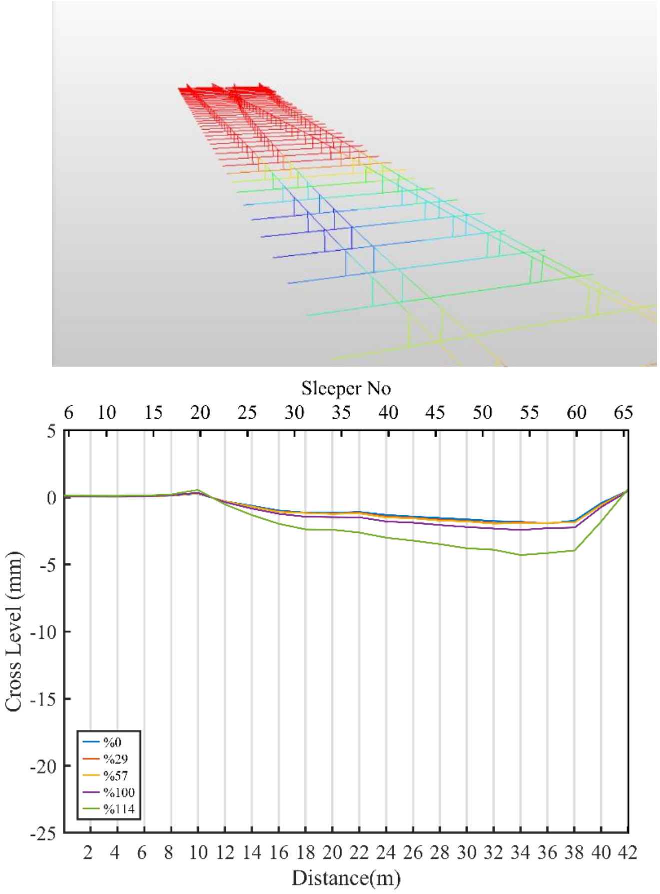

Fig. 3. A graphical demonstration of vertical displacement in the vicinity of the bearer with no.30, where blue color represents the lowest (top). Cross-level values in different surface water levels(bottom)

3.2 The Effect of Washed Away Ballast at Switch Panel

As mentioned previously, railway track could be suffered from washed away ballast in the event of flooding. In that case, the bearers lose ground support and hang on the rails. It should be reminded that in this scenario, it is assumed that all ballast particles at washed away section are dragged and therefore, no partial support is observed for the bearers on the contrary to the reality where partial support at some bearers could be observed. Here, three different scenarios have been considered in the simulation such that the length of the washed away section is 3, 5 and 10 bearers.

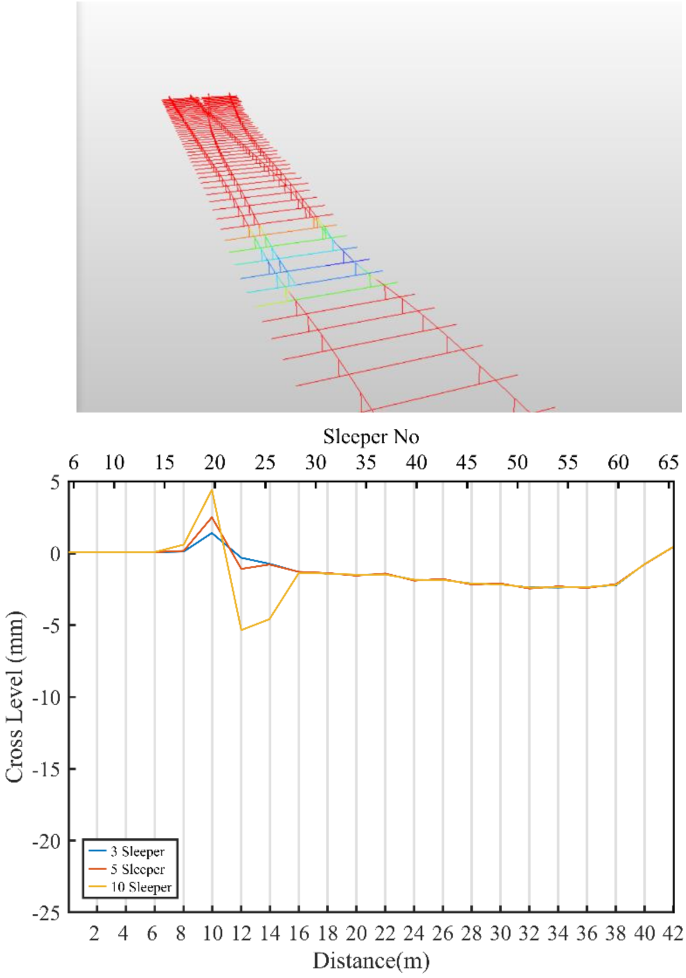

Fig. 4. A graphical demonstration of vertical displacement in the vicinity of the bearer with no.18, where blue color represents the lowest (top). Cross-level values for 3, 5 and 10 bearers at switch panel subjected to washed away ballast (bottom).

As presented in Fig. 3, the number of washed away ballast have negative impacts on the cross-level values significantly at the switch section. Interestingly, the cross-level have a positive value first (Fig. 3 top) and then a negative value. To explain that, the working principles of a turnout should be considered. When a vehicle is directed to a certain route, one switch blade is opened. Simultaneously, the other is closed and stuck to the stock rail. Hence the support conditions of railway track change with the location of switchblades. The open switchblade is positioned away from the left rail and produce a new support point that affects load distribution. Consequently, the left rail is relatively stiffer first and have positive cross-level. However, the stiffness value becomes higher at the right rail side, later and negative cross-level value becomes significant.

The number of unsupported bearer due to washed away ballast has a direct contribution to the magnitude of cross-level. Maximum cross-level, around 10 mm, is observed when ten bearers are unsupported. It is important that vehicle might become unstable at that point since the direction cross-level suddenly changes from positive to negative and bearers are unsupported. In other cases, there is a small disturbance between bearers with the numbers of 15 and 25. The rest of turnout have similar behavior to the supported scenario as mentioned previously. In general, the cross-level parameters are still in the permissible range concerning twist calculation in the manual [35].

3.3 The Effect of Washed Away Ballast at Crossing Panel

The crossing panel is the point where high-frequency high magnitude impact forces occur at the crossing nose, a position on the right rail. These forces present challenges in term of track and vehicle safety and integrity of the system. As indicated in [34], these forces could be up to 3 times higher than normal static wheel load. Interestingly, in previous sections, the cross-level value in this section exhibits negligible behavior. It seems that the contribution of impact forces into cross-level values seems to be limited. Hence, in Fig. 4 below, the cross-level values, the highest among all scenarios, are believed to result from the stiff structure of the crossing panel (Fig. 4 top). In other words, the loss of ballast support has a less negative impact on the right rail at crossing panel, particularly in comparison to the case of washed away ballast at switch panel. As a consequence, the left rail has a relatively larger displacement which produces more cross-level.

Fig. 4 also illustrates that the contribution of the number of unsupported bearers is evident as the highest magnitude is presented in the case of 10 unsupported bearers. In that case, the cross-level values are acceptable in [35]. However, it should be repaired in 10 days according to [36].

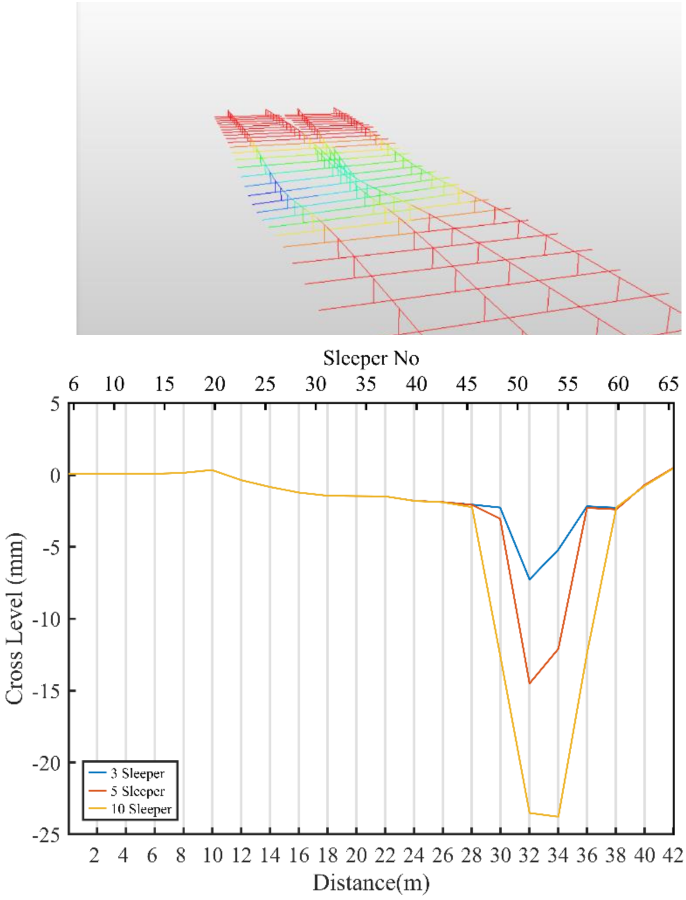

Fig. 5. A graphical demonstration of vertical displacement in the vicinity of the bearer with no.50, where blue color represents the lowest (top). Cross-level values for 3, 5 and 10 bearers at crossing panel subjected to washed away ballast (bottom).

4 Conclusions

This study provides new insights into the understanding of the dynamic behavior of a turnout system during an unprecedented event of flooding. The outcome of the study could be summarized as follows. First of all, the asymmetric topology of a turnout causes a negative cross-level even in a dry environment, showing that the loading conditions on rails are not balanced. A further investigation is recommended to evaluate whether it is beneficial to increase the ballast stiffness under the left rail/ stock rail or not. Secondly, the effect of unsupported bearers on cross-level due to washed away ballast is obvious. An expansion of washed away section causes the more severe cross-level difference. Hence, based on the current simulation and its limitations, it could be concluded that the risk of a derailment is highly likely with the expansion. Therefore, it is recommended that train operation be terminated instantly with any suspicion of washed away ballast, particularly at crossing panel, for safety concerns. Thirdly, the impact of surface water levels seems to be indistinctive below the normalized water level. In other words, the ballast structure seems to provide significant support unless the ballast bed is not fully under water. However, the validity of this conclusion is strongly related to the validity of the study from which the ballast parameters were collected.

Finally, outcomes of this study indicate that turnouts could inherently suffer from twist defects under vehicle loading owing to its asymmetrical structure, a potential cause of a derailment. Particularly taking the amplification characteristic of high speeds into account, further studies should be conducted at different vehicle speeds in different scenarios to improve the understanding of dynamic behavior of a turnout system in the case of flooding.

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References

1. Virgin Hyperloop homepage, https://virginhyperloop.com/, last accessed 28.11.2020.
2. Kaewunruen, S. and Rungskunroch, P.: A through-life evaluation of end-of-life rolling stocks considering asset recycling, energy recovering, and financial benefit. Journal of cleaner production, 212,1008-1024 (2019).
3. Kaewunruen, S., Sussman, J.M. and Einstein, H.H.: Strategic framework to achieve carbon-efficient construction and maintenance of railway infrastructure systems. Frontiers in Environmental science, 3, 6 (2016).
4. Krezo, S., et al.: Field investigation and parametric study of greenhouse gas emissions from railway plain-line renewals. Transportation Research Part D: Transport and Environment, 42, 77-90 (2016).
5. Ngamkhanong, C., Kaewunruen, S. and Costa, B.J.A.: State-of-the-art review of railway track resilience monitoring. Infrastructures, 3(1), 3 (2018).
6. Kaewunruen, S., Sussman, J.M. and Matsumoto, A.: Grand challenges in transportation and transit systems. Frontiers in built environment, 2, 4 (2016).
7. Ngamkhanong, C., Nascimento, A.T. and Kaewunruen, S.: Economics of track resilience. in IOP Conference Series. Materials Science and Engineering, (2019).
8. Kaewunruen, S.: Monitoring in-service performance of fibre-reinforced foamed urethane sleepers/bearers in railway urban turnout systems. Structural Monitoring and Maintenance, 1(1), 131 (2014).

9. Hamarat, M., et al.: The Effect of Unsupported Sleepers/Bearers on Dynamic Phenomena of a Railway Turnout System under Impact Loads. Applied Sciences, 10(7), 2320 (2020).
10. Kaewunruen, S., R. You, and M. Ishida.: Composites for timber-replacement bearers in railway switches and crossings. Infrastructures, 2(4), 13 (2017).
11. Sengsri, P., et al.: Experimental and Numerical Investigations into Dynamic Modal Parameters of Fiber-Reinforced Foamed Urethane Composite Beams in Railway Switches and Crossings. Vibration, 3(3), 174-188 (2020).
12. Dindar, S., S. Kaewunruen, and An,M.: Bayesian network-based human error reliability assessment of derailments. Reliability Engineering & System Safety, 197, 106825 (2020).
13. Andersson, C. and Dahlberg,T.: Wheel/rail impacts at a railway turnout crossing. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 212(2), 123-134 (1998).
14. Ekberg, A. and Paulsson, B.: INNOTRACK: concluding technical report. 2010: International Union of Railways (UIC).
15. Esveld, C.: Modern railway track. 2nd edition. MRT-productions, Netherlands (2001).
16. Grossoni, I., et al.: Dynamics of a vehicle–track coupling system at a rail joint. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 229(4), 364-374 (2015).
17. Kassa, E. and Nielsen, J.C.: Dynamic interaction between train and railway turnout: full-scale field test and validation of simulation models. Vehicle System Dynamics, 46(S1), 521-534 (2008).
18. Manalo, A., et al.: A review of alternative materials for replacing existing timber sleepers. Composite Structures, 92(3), 603-611 (2010).
19. Sae Siew, J., O. Mirza, and Kaewunruen,S.: Torsional effect on track-support structures of railway turnouts crossing impact. Journal of Transportation Engineering, Part A: Systems, 143(2), 06016001 (2017).
20. Wei, Z., et al.: Wheel–rail impact at crossings: relating dynamic frictional contact to degradation. Journal of Computational and Nonlinear Dynamics, 12(4), (2017).
21. Kaewunruen, S. and Q. Lian.: Digital twin aided sustainability-based lifecycle management for railway turnout systems. Journal of Cleaner Production, 228, 1537-1551 (2019).
22. Wang, P.: Design of high-speed railway turnouts: theory and applications. Academic Press, USA (2015).
23. Kaewunruen, S., et al.: Asymetrical influences on nonlinear dynamics of railway turnout bearers. 2017.
24. Kaewunruen, S. and Tang, T.: Idealisations of dynamic modelling for railway ballast in flood conditions. Applied Sciences, 9(9), 1785 (2019).
25. Li, D. and Kaewunruen, S.: Effect of extreme climate on topology of railway prestressed concrete sleepers. Climate, 7(1), 17 (2019).
26. Ludvigsen, J. and Klæboe, R.: Extreme weather impacts on freight railways in Europe. Natural hazards, 70(1), 767-787 (2014).
27. Binti Sa'adin, S.L., Kaewunruen, S. and Jaroszweski, D.: Operational readiness for climate change of Malaysia high-speed rail. in Proceedings of the Institution of Civil Engineers-Transport, (2016).
28. Binti Sa’adin, S.L., Kaewunruen, S. and Jaroszweski, D.: Risks of Climate Change with Respect to the Singapore-Malaysia High Speed Rail System. Climate, 4(4), 65 (2016).
29. Binti Sa’adin, S.L., Kaewunruen, S. and Jaroszweski, D.: Heavy rainfall and flood vulnerability of Singapore-Malaysia high speed rail system. Australian Journal of Civil Engineering, 14 (2), 123-131 (2016).

30. Kaewunruen, S., et al.: Vulnerability of structural concrete to extreme climate variances. Climate, 6(2), 40 (2018).
31. Dindar, S., et al.: Bayesian Network-based probability analysis of train derailments caused by various extreme weather patterns on railway turnouts. Safety science, 110, 20-30 (2018).
32. Quinn, A., et al.: Rail Adapt: Adapting the Railway for the Future. A Report for the International Union of Railways (UIC), (2017).
33. Daily Mail, https://www.dailymail.co.uk/news/article-5932793/24-die-318-injured-Turkey-train-derails-following-heavy-rain.html, last accessed 2020 28.11.2020.
34. Hamarat, M., et al.: New insights from multibody dynamic analyses of a turnout system under impact loads. Applied Sciences, 9(19), 4080 (2019).
35. RailCorp: TMC 203-Track Inspection in Engineering Manual-Track. Australia (2019).
36. Railtrack Plc.: Twist Faults. The Permanent Way Institution, Birmingham (2002).