Dynamic performance of concrete turnout bearers and sleepers in railway switches and crossings

Kaewunruen, Sakdirat; Ishida, Tetsuya; Remennikov, Alex

DOI:
10.1520/ACEM20170103

Dynamic performance of concrete turnout bearers and sleepers in railway switches and crossings

Sakdirat Kaewunruen[1*], PhD; Tetsuya Ishida[2], PhD; Alex M Remennikov[3], PhD

[1]Senior Lecturer in Railway and Civil Engineering, School of Engineering, the University of Birmingham, 52 Pritchatts Road, Birmingham, B152TT, UK, s.kaewunruen@bham.ac.uk.

[2]Professor of Concrete Engineering, Department of Civil and Environmental Engineering, the University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan, tetsuya.ishida@civil.t.u-tokyo.ac.jp

[3]Head of School and Professor of Structural Engineering, School of Civil, Mining and Environmental Engineering, University of Wollongong, Northfield Avenue, North Wollongong, NSW 2502 Australia. alexrem@uow.edu.au

ABSTRACT: With constant changes of geometry and alignment, wheel-rail forces, track and operational parameters, railway infrastructures are exposed to nonlinear actions by nature. A detrimental type of the loading condition that causes cracking in the railway concrete bearers in switches and crossings is the dynamic transient wheel force. The transient wheel forces are often due to the wheel-rail transfer over the dipped trajectory at a crossing nose. It is often found that most track deterioration incurs at the crossing panel. The turnout bearers crack and break. The ballast degradation then causes differential settlement and later aggravates impact forces acting on partial and unsupported sleepers and bearers. In addition, localised ballast

[*] Corresponding author. E-mail: s.kaewunruen@bham.ac.uk

breakages underneath any railseat increase the likelihood of centre-bound cracks in railway sleepers and bearers due to the unbalanced support. This paper investigates the dynamic performance of standard-gauge concrete bearers at crossing panel, taking into account the nonlinear tensionless nature of ballast support. A finite element model was established and calibrated using static and dynamic responses using past experimental results. In this paper, nonlinear phenomena due to topologic asymmetry on both sagging and hogging behaviours of crossing bearers are firstly highlighted. In addition, it is the first to demonstrate the effects of dynamic load impulses on the design consideration of turnout bearers in crossing panel. The outcome of this study will benefit the railway turnout design and maintenance criteria in order to improve train-turnout interaction and reduce maintenance costs.

Keywords: Dynamics; concrete bearers; crossties; impact loading; switches and crossings; turnout systems

INTRODUCTION

In ballasted track systems, railway sleepers (also called 'railroad tie' in North America) are a safety-critical element of railway track structures. Their fundamental roles are to redistribute loads from the rails to the underlying ballast bed and to secure track gauge for safe passage of trains. Based on the current design approach, the design life span of the concrete sleepers is targeted at around 50 years in Australia, Asia and North America; and around 70 years in Europe [1-5]. Fig. 1 shows a typical ballasted railway track and its main critical components. There have been a number of previous investigations on the railway sleeper models [6-9]. Most of the models employed the concept of beam on elastic foundation where a sleeper is laid on the elastic support, acting like a series of springs. It is found that only vertical stiffness is sufficient to simulate the ballast support condition because the lateral stiffness seems to play an insignificant role in sleeper's bending responses [7, 10, 11]. In practice, the lateral force is moderated by alignment and geometry design to be less than 20% of vertical force and the anchorage of fastening has been designed to take care of such the lateral actions [12, 13]. In fact, field measurements suggest a diverse range of sleeper flexural behaviors, which are largely dependent on the support condition induced by ballast packing and tamping [14-17]. However, it is still questionable at large whether modern ballast tamping process is effective and it could enable adequate symmetrical support for sleeper at railseat areas. In reality, the ballast is tamped only at the railseat areas. The ballast at the mid span is left loosening, with the intention to reduce negative bending moment effect on sleeper at the mid span, which is the cause of centre-bound cracks. Over time, the dynamic track settlement induces ballast densification and the sleeper mid-span comes into contact or is fully supported by ballast until the track geometry is restored by resurfacing activity (i.e. re-tamping).

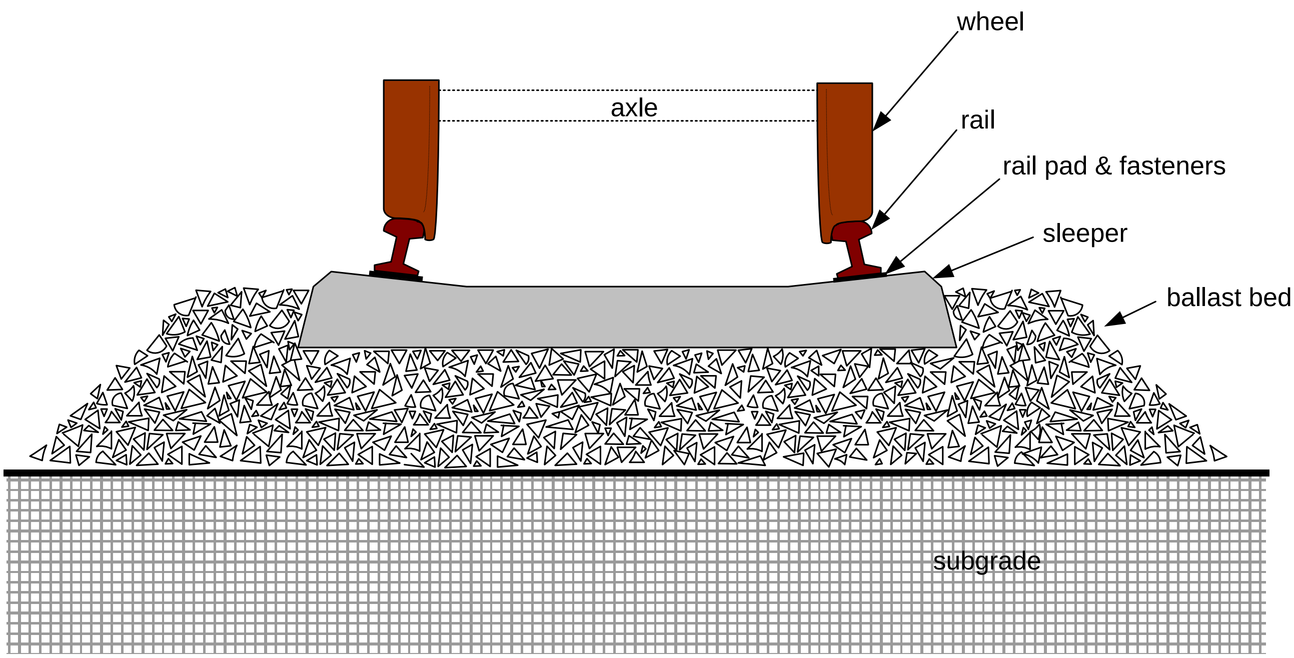
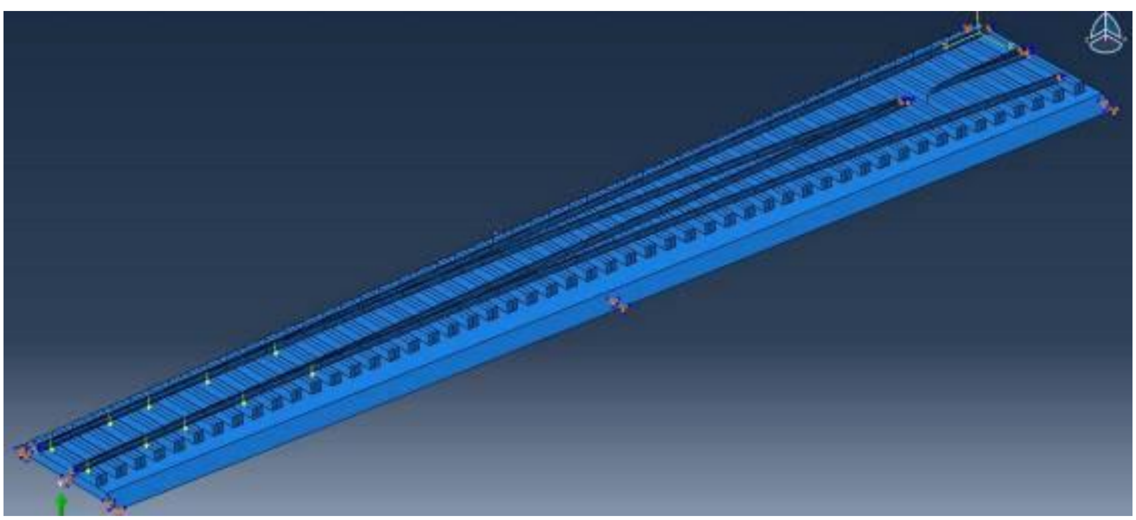


Fig. 1. Typical ballasted railway track components.



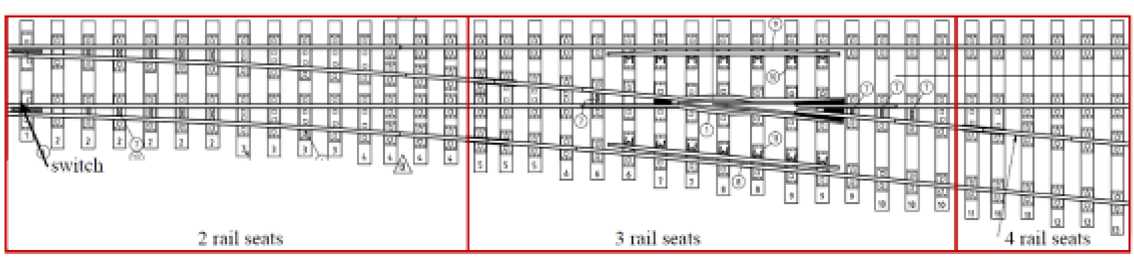


Fig. 2. Typical turnout system layout [15].

Railway turnout (or called ‘switches and crossings’) is a special track system used to divert a train from a particular direction or a particular track onto other directions or other tracks. It is a structural grillage system that consists of steel rails, points (or called ‘switches’), crossings (or called ‘frogs’), steel plates, rubber pads, insulators, fasteners, screw spikes, beam bearers (either timber, polymer, steel or concrete), ballast and formation, as shown in Figure 2. Its structural layers are designed consistently to an open plan track. There are two types of turnouts, a conventional turnout and a tangential turnout. Standard conventional turnouts are designed typically for straight main line track. The combination of switch length, heel angle and cross rate defines the turnout type, and they all typically have the same components. Tangential turnouts are defined by the radius of the turnout. Components in a tangential turnout vary as manufacturers place their own designs over the standard configuration. The traditional turnout structure generally imparts high impact forces on to its structural members because of its blunt geometry and mechanical connections between closure rails and switch rails (i.e. heel-block joints). In contrast, the structural behavior of turnout bearers has not been fully investigated. A railway turnout system have generally been analysed the using a grillage beam method [18, 19]. Although the simplification is useful, such a method could not adequately assist in the failure analyses of turnout components. In some cases, the results using the grillage beam method seem to have discrepancies with the field observations where the maximum bending and shear forces were evident within the crossing panel [20, 21]. A number of research has been conducted to locate the critical section within a turnout, and many of which conclude that the critical section is located specifically at the crossing panel at either v-crossing or k-crossing [22-25].

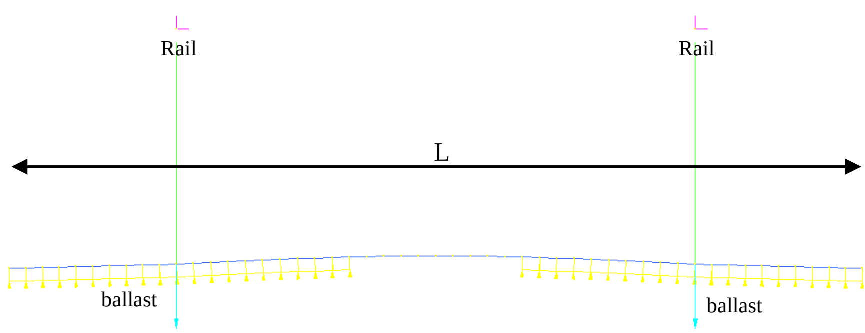
Although it is clear that the turnout bearers are topological asymmetry, such the aspect has never been fully investigated. This paper presents an advanced railway concrete bearer modeling capable of analysis into the effect of topological asymmetry on the positive and negative flexural responses of railway bearers. This study is the first to focus on the nonlinear transient response of asymmetric railway bearers under various spectra of ballast support conditions, in comparison with the current design method in accordance with the design standards. The insight into the dynamic performance of asymmetric bearers will help civil and track engineers to effectively and efficiently carry out predictive maintenance of railway turnout systems.

FINITE ELEMENT MODEL

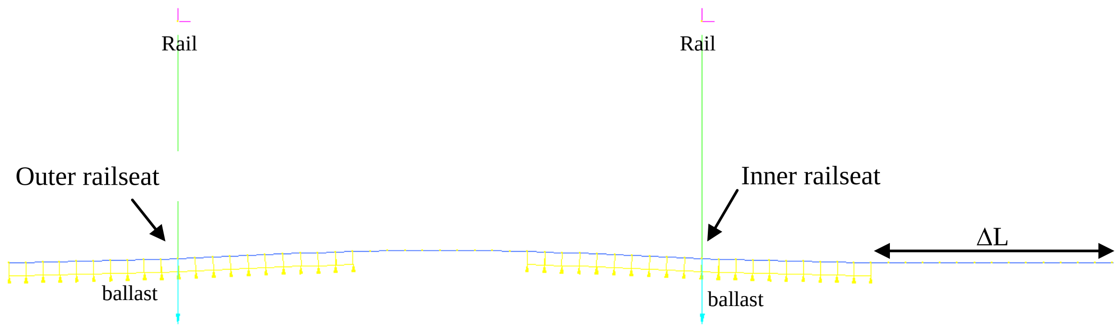
Previous extensive studies established that the two-dimensional Timoshenko beam model is the most suitable option for modeling concrete sleepers and rails under vertical loads [6-8]. In this investigation, the finite element model of concrete sleeper (optimal length) has been previously developed and calibrated against the numerical and experimental modal parameters [11, 26, 27]. Fig. 3 shows the two-dimensional finite element model for an in-situ railway concrete sleeper. Using a general-purpose finite element package STRAND7 [28], the numerical model included the beam elements, which take into account shear and flexural deformations, for modeling the concrete sleeper. The trapezoidal cross-section was assigned to the sleeper elements.

The rails and rail pads at railseats were simulated using a series of spring. In this study, the sleeper behaviour is stressed so that very small stiffness values were assigned to these springs.

In reality, the ballast support is made of loose, coarse, granular materials with high internal friction. It is often a mix of crushed stone, gravel, and crushed gravel through a specific particle size distribution. It should be noted that the ballast provides resistance to compression only. As a result, the use of elastic foundation in the current standards in Australia and North America [1, 14, 18, 29-31] does not well represent the real uplift behaviour of sleepers in hogging moment region (or mid span zone of railway sleeper). In this study, the support condition was simulated using the tensionless beam support feature in Strand7 [28]. This attribute allows the beam to lift or hover over the support while the tensile supporting stiffness is omitted. The tensionless support option can correctly represent the ballast characteristics in real tracks [28]. Table 1 shows the geometrical and material properties of the finite element model. It is important to note that the parameters in Table 1 give a representation of a specific rail track. These data have been validated and the verification results have been presented elsewhere [9, 11, 26, 31, 32]. This study extends significantly from the recent work [33].

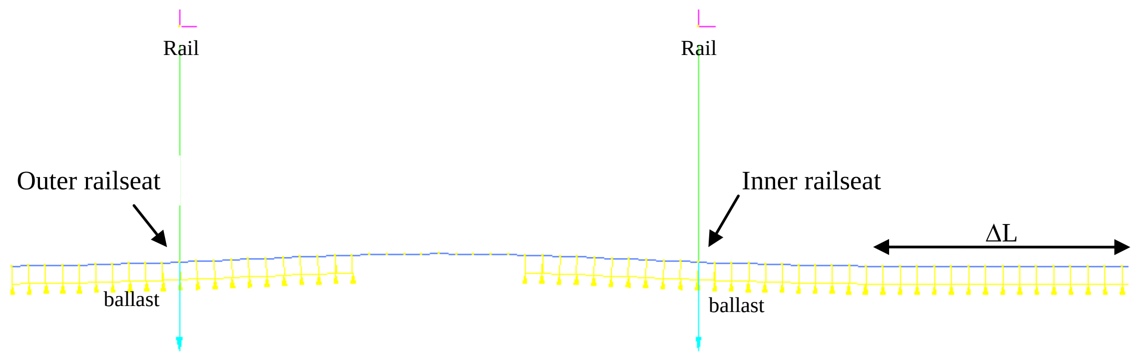


a) symmetrical topology

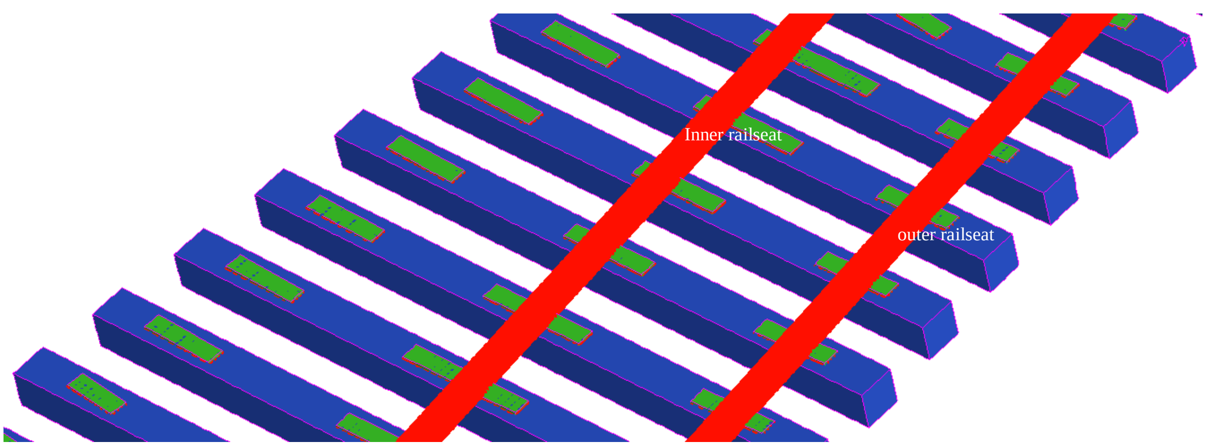


b) asymmetrical topology (overhanging)

Fig. 3. STRAND7 finite element model of a concrete bearer



c) asymmetrical topology (fully supported)



d) an example of full turnout modelling

Fig. 3. STRAND7 finite element model of a concrete bearer

Based on our critical literature review, the flexural influences on railway concrete bearers in a turnout system (switch and crossing) due to the variations of ballast support conditions together with the asymmetric topology of bearers has not yet been addressed by the past researchers [18, 19]. Especially when the uplift behaviour due to ballast's nonlinear tensionless support in hogging region of sleepers is considered, a finite element analysis is thus required to supersede the simple manual calculation. For this study, the numerical simulations considering nonlinear uplift of sleeper have been extended to conduct the analyses using the nonlinear solver in STRAND7. The nonlinear analysis makes use of an iteration algorithm to evaluate the non-uniform contact between sleeper and ballast, which is a type of nonlinear boundary condition. The effects of asymmetric topology of concrete bearers on their flexural responses in a turnout system can be evaluated. The length of bearer varies from 2.5m to 4.0m, which is practically common in the 2 and 3 rail-seats sections (see Fig. 2). After considering the field report [17, 20, 31], the study will focus on the dynamic behavior of bearers in crossing panel (section 3 in Fig. 2) since impact damage on bearers are often reported (see Fig. 4).

Table 1 Engineering properties of the standard sleeper used in the modeling validation

Parameter lists*		
Flexural rigidity	$EI_c = 4.60$, $EI_r = 6.41$	MN/m^2
Shear rigidity	$\kappa GA_c = 502$, $\kappa GA_r = 628$	MN
Ballast stiffness	$k_b = 13$	MN/m^2
Rail pad stiffness	$k_p = 17$ $k_p = 68$	MN/m (vertical) MN/m (lateral)
Sleeper density	$\rho_s = 2{,}750$	kg/m^3
Sleeper length	$L = 2.5$	m
Rail gauge	$g = 1.5$	m

*subscript *c* indicates the centre of sleeper and *r* is at the railseat.

Fig. 4. Damage of concrete bearer (3.5-4m) underneath a v-crossing panel

RESULTS AND DISCUSSION

Based on the reference data in Table 1, static behaviors of asymmetrical bearers can be identified. Tables 2 and 3 present the static bending moment envelops along the bearer when subjected to the equal wheel loads of 100kN at both railseats, in comparison with the standard design moments. In accordance with AS1085.14 [1], the design maximum positive bending moment at the rail seat = 12.50 kNm, while the centre negative design bending moment = 6.95 kNm (if considered half support) or =12.50 kNm (if considered full support). It is typical that the positive and negative moments are associated with the railseat and mid-span sections, respectively. It shows that the standard design moments provide relatively conservative results (or, the real action is slightly lesser than the design capacity). The standard design moment at mid span is about half between the other two cases (see Fig. 3).

Table 2 Maximum bending moment of overhanging bearer

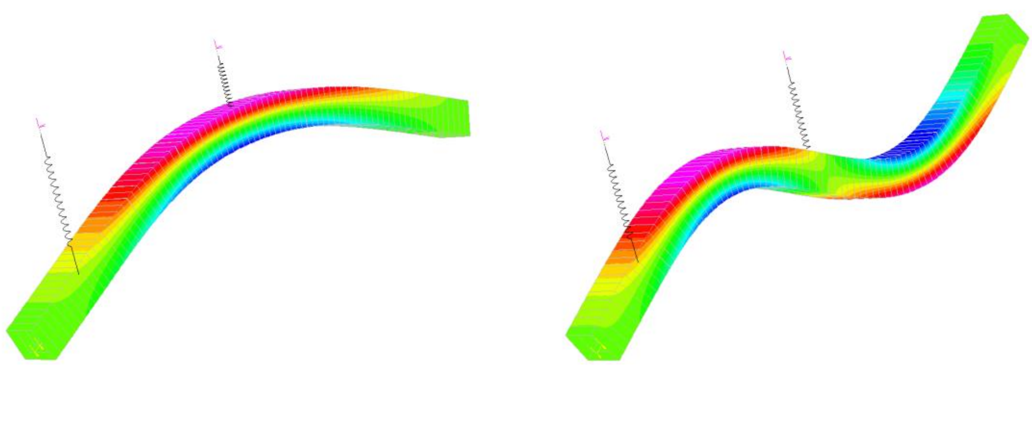
ΔL/L (overhanging)	**At railseat (kNm)**		**At mid span (kNm)**	
	M*	M^*/M_{Design}	M*	M^*/M_{Design}
0	+ 11.93	0.95	- 0.95	0.14
10%	+ 11.93	0.95	- 0.95	0.14
20%	+ 11.93	0.95	- 0.96	0.14
30%	+ 11.93	0.95	- 0.96	0.14
40%	+ 11.93	0.95	- 0.96	0.14
50%	+ 11.93	0.95	- 0.96	0.14
60%	+ 11.93	0.95	- 0.96	0.14

Table 3 Maximum bending moment of fully-supported bearer

ΔL/L (full support)	**At railseat (kNm)**		**At mid span (kNm)**	
	M*	M^*/M_{Design}	M*	M^*/M_{Design}
0	+ 11.93	0.95	- 0.95	0.14
10%	+ 15.16	1.21	+ 2.22	0.32
20%	+ 16.50	1.32	+ 3.15	0.45
30%	+ 16.74	1.34	+ 3.29	0.47
40%	+ 16.74	1.34	+ 3.29	0.47
50%	+ 16.74	1.34	+ 3.29	0.47
60%	+ 16.74	1.34	+ 3.30	0.47

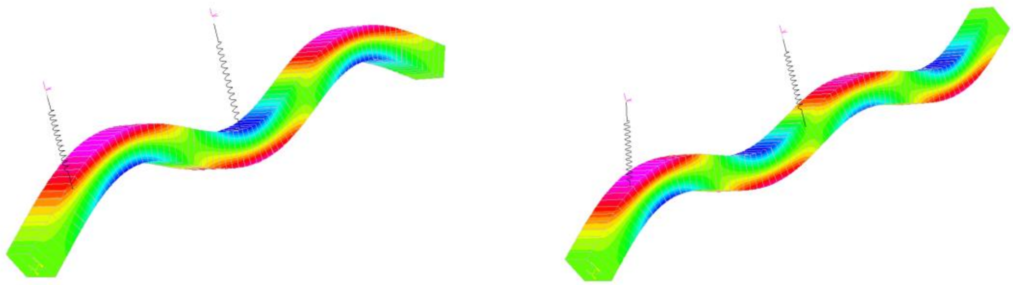
Based on the static results in Tables 2 and 3, it is clear that the influence of the asymmetrical topology is pronounced when there is a contact between bearer and ballast layer. Considering a field investigation, such the contact could occur when there is a differential settlement on the mainline track (or run-through turnout road). This differential settlement is not uncommon when the track is not well maintained. Once the ballast-bearer contact establishes, the bearers will take additional static bending moment action at the inner railseat up to 34%.

Using nonlinear eigenvalue analysis (based on Newton Raphson's algorithm), the generalized dynamic modeshapes of the bearers can be identified as illustrated in Figure 5. The natural frequencies of the asymmetrical bearers can be observed in Tables 4 and 5. It can be seen that the topology of bearer plays a key role in dynamic natural frequencies and the corresponding mode shapes of the bearers. Overhanging bearers tend to be relatively much affected by the topology factor in comparison with the dynamic behavior of fully supported bearers. Fig. 6 shows the dynamic softening behavior of the turnout bearers with asymmetrical topology. It is clear that the dynamic softening is more pronounced at a higher frequency range.



a) 1st bending b) 2nd bending

Fig. 5. Normalized example of dynamic modeshapes of turnout bearer



c) 3rd bending　　　　d) 4th bending

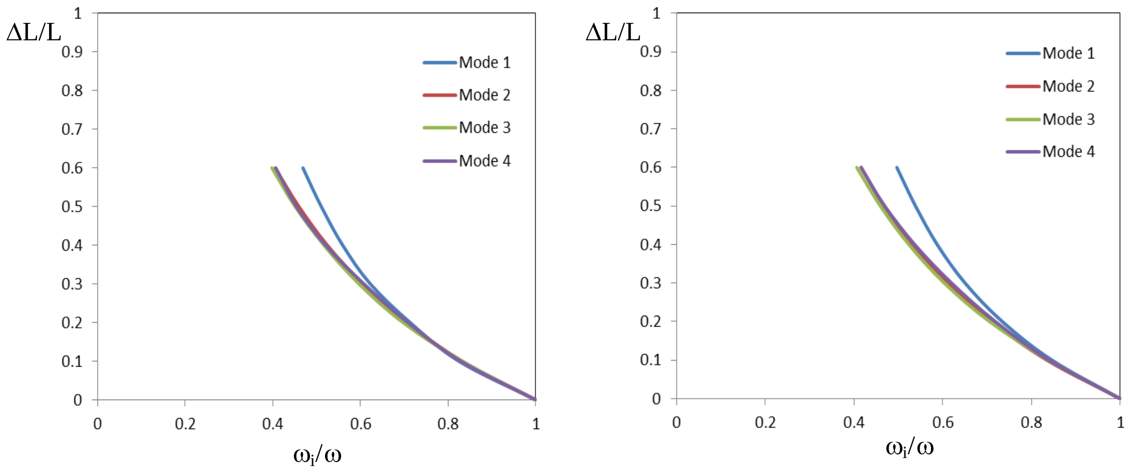
Fig. 5. Normalized example of dynamic modeshapes of turnout bearer

Table 4 Natural frequencies of overhanging bearer

ΔL/L (overhanging)	**Resonances (Hz)**			
	Mode 1	Mode 2	Mode 3	Mode 4
0	143	370	714	1155
10%	118	308	594	957
20%	102	261	498	818
30%	89	224	426	702
40%	80	194	369	601
50%	73	170	322	524
60%	67	150	284	470

Table 5 Natural frequencies of fully-supported bearer

ΔL/L (full support)	**Resonances (Hz)**			
	Mode 1	Mode 2	Mode 3	Mode 4
0	143	370	714	1155
10%	121	309	599	970
20%	105	263	504	830
30%	93	227	431	716
40%	84	197	374	620
50%	77	173	328	542
60%	71	154	290	480



a) Overhanging b) fully supported

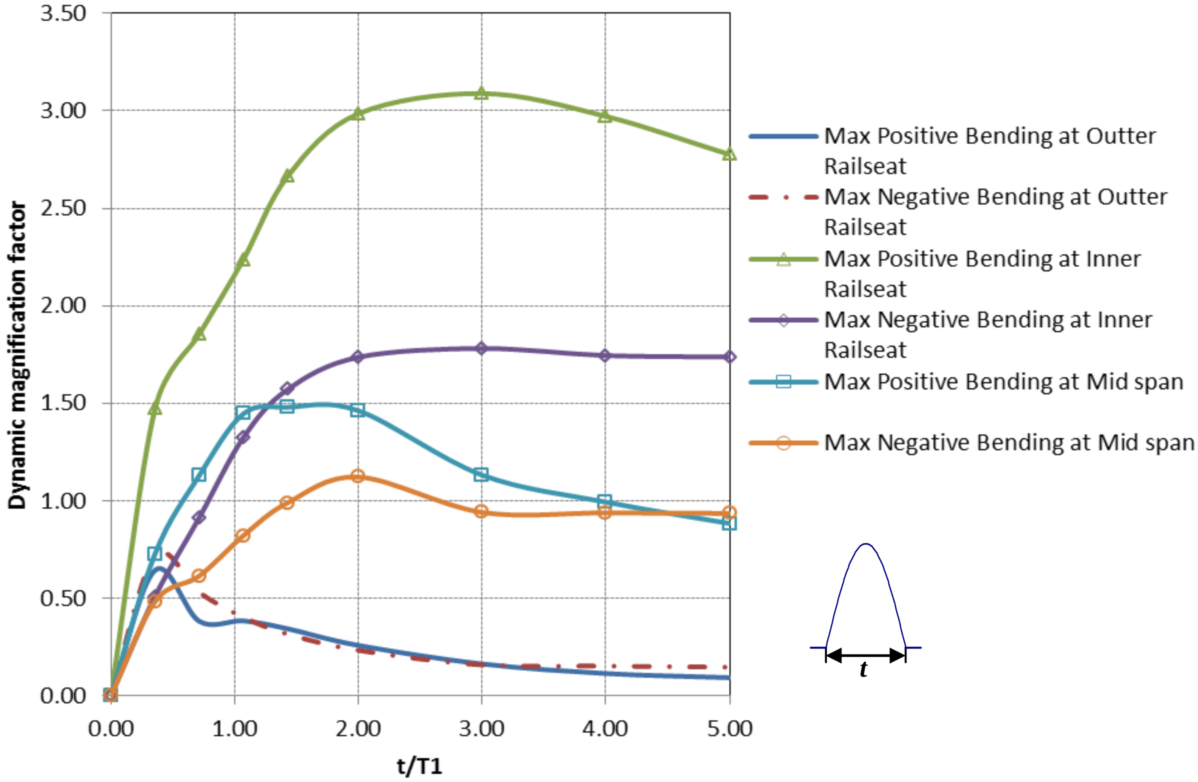
Fig. 6. Frequency ratios of turnout bearer

To our knowledge, the nonlinear transient analysis of railway bearers in a turnout system with the variation of sinusoidal pulse durations has not yet been adequately addressed by railway engineering community. To develop a predictive maintenance of the railway concrete bearers, a better understanding into their transient responses and dynamic performance is imperative. The numerical simulations are conducted using the nonlinear transient solver in STRAND7, in order to evaluate the transient responses of the asymmetrical bearers in switches and crossings. For the parametric comparison studies (benchmarking purpose), the common parameters of an impulse include the constant maximum magnitude of 100kN while the duration (t) of the sinusoidal pulse varies from 1ms to 35ms. The wheel load on the stock rail (outter rail) has been kept static (as non-structural mass), whilst transient effects of the wheel load over crossing nose are investigated. In this study, Rayleigh damping ratio of 0.2 for sleeper-ballast interacton has been adotped as reported in the field [26, 27].

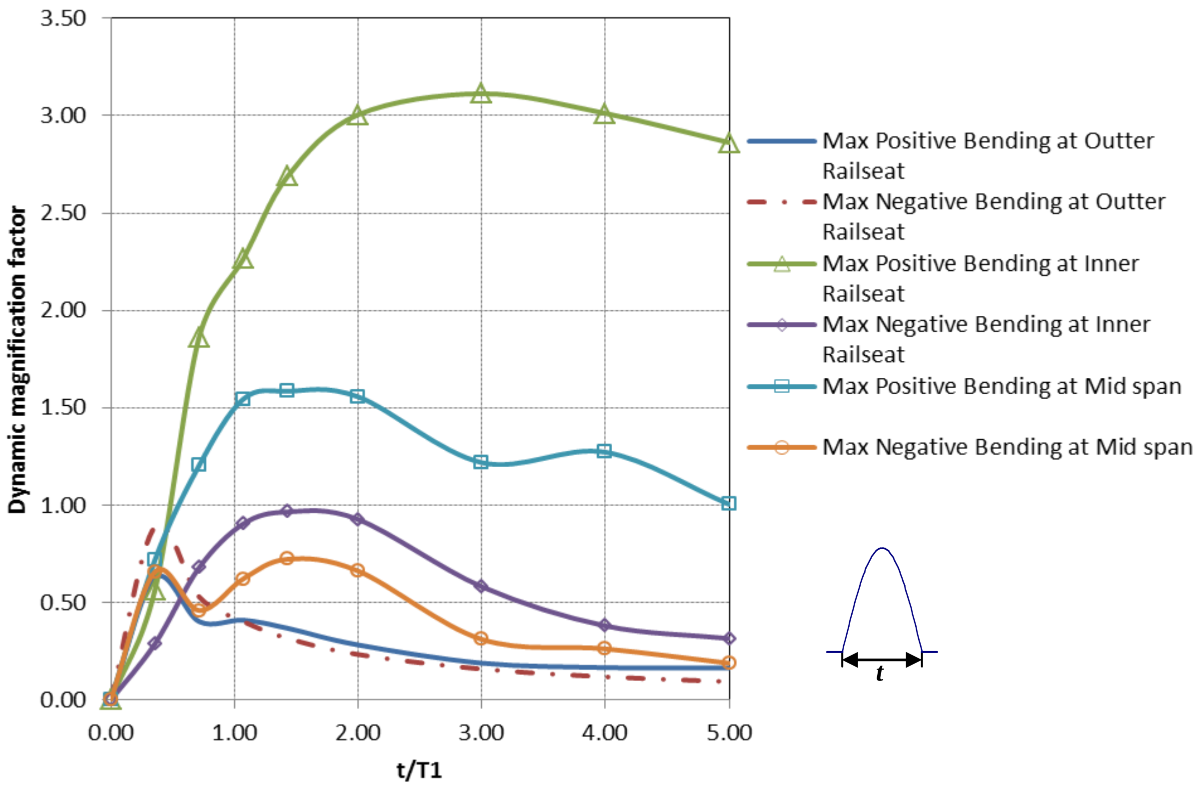
Samuels and Palesano [32] and Kaewunruen and Remennikov [26] agreed that the first three flexural resonances of railway concrete sleepers substantially affect their durability themselves. The first dynamic bending mode of railway concrete sleeper (associated with the impact duration of about 7ms) magnifies the flexural responses at mid span of the railway concrete sleeper. The second and the third vibration modes (associated with the impact durations of roughly 3ms and 1ms, respectively) seem to magnify the flexural behaviours of the railway concrete sleeper at both rail seats. In this study, the forth bending mode has been included for sensitivity identification. It is nopted that, in general, the pulse duration of about 1.0ms to 5.0ms can often be associated with P1 force, and the pulse with 5.0ms to 20ms can be correlated to P2 force. The P1 and P2 forces are the resulting impact loading often derived from wheel-rail interaction over the transfer zone (over a crossing nose). Note that for the pulse length t about 1.0ms to 2.0ms, it can be correlated to t/T_1 = 0.19, t/T_2 = 0.50, and t/T_3 = 1.00.

Figure 7 presents the parametric effect of the load duration ratios between the applied pulse durations and the lowest flexural period on the dynamic magnification factor of the railway concrete sleeper. The dynamic magnification factor is obtained from the ratio between dynamic and static bending moments (based on the standard calculations) at the specific cross-sections. It appears that the maximum dynamic magnification factors for both positive and negative bending moments at outter rail seats is less than 1.0 and the maximum occurs due to the 2.0ms pulse, which is associated with the forth bending mode resonance of the railway concrete bearers. It is subsequently fade away when the pulse durations are larger. For the dynamic behaviours of overhanging bearers at mid span (see Figure 7a), it is clear that the maximum positive and negative bending moments tend to peak above 1.0 at the pulse duration ratio between 1.0 and 2.00. These pulses are correlated to the beare's second bending resonance. For the negative bending moment at inner rail seat, the dynamic magnification factor of overhanging bearers shows the peak over the long period when corresponded to the first bending mode resonance of the railway concrete bearers. For overhanging bearers, it is found that the maximum dynamic response under positive bending moment at inner railseat can potentially cause the damage of the bearers. The dynamic magnification factor at the inner railseat reaches just above 3.0 especially when the bearers are excited by the pulses resonating the first and second bending modes of vibration.

The transient behaviours of the overhanding bearers are quite similar to those of the full support bearers. However, it is clear that the ballast condition plays a key role on the dynamic performance of asymmetrical bearers especially at inner railseat and at mid span. The overhanging affects the negative bending behaviours at inner railseat and at midspad. At outter railseats, the dynamic magnification factor prevails for a single peak at the fourth bending resonance, and at the pulse duration ratio about 2ms. In addition, it exhibits that, for the bending behaviours at mid span of the railway bearers, the maximum peak occurs at the frist and second bending resonance. This behaviour also resembles the negative dynamic response of the full support bearer at inner railseat. However, it can be seen that the effect of pulse duration ratios larger than 2.0 become significant to the maximum positive bending performance of full-support bearers at railseat, with the dynamic magnification factors above 3.0.



a) overhanging



b) full support

Fig. 7. Dynamic magnification factor for the railway concrete sleeper to transient loadings

CONCLUSIONS

In this study, critical structural effects of ballast conditions and asymmetric topology on the dynamic flexural responses and impact behaviors of the railway concrete sleepers and bearers in a turnout system (switches and crossings) are emphasized. The finite element model of bearers, which was established and calibrated using experimental results earlier, is utilised in this study. The influences of the variation of ballast support conditions at bearer end together with the asymmetric length of sleepers on the dynamic bending of the railway bearers were highlighted in comparison with the standard design. The nonlinear solver in STRAND7 was employed to cope with nonlinear sleeper/ballast contact mechanics using Newton Raphson method. Under static and free vibration conditions for overhanging and supported bearers, the numerical results exhibit that the bending moment resultants are barely affected by topological aspects when the ballast-sleeper contact is not established. The standard design bending moments tend to be overestimated for the overhanging bearer, whilst they can be highly underestimated when bearer end is laid on ballast. Generally, positive bending moments at inner railseat of bearer have generally high sensitivity to the spectrum of ballast support conditions in comparison with the more pronounced influence of sleeper length. In such case, the nominal bending moment at inner railseat could be larger than the structural capacity of sleeper and resulted in structural cracks and failure. In contrast, such behavior is insignificant and tolerable for overhanging bearers. By understanding the free vibration behavior of bearers, it is clear that the asymmetrical topology induces dynamic softening in the turnout bearers. This implies that the asymmetrical bearers are prone to damage under high-intensity impact loading, which could trigger and sweep through various resonant frequencies of the turnout bearers. The insight in these structural behaviors of the asymmetrical bearer has raised the awareness of track engineers for better design and maintenance of switch and crossing support structures.

The parametric study indicates that the dynamic bending moment resultants are affected considerably by the different transient durations. In general, the transient loading excites the railway concrete bearers and they vibrate. It can be found that at the lowest, second, third and fourth bending modes of vibration, the dynamic flexural responses of the asymmetrical bearers could be remarkably amplified, especially at the inner railseats. The critical frequencies (or the inverse of period) as can be clearly determined through the peak spectra of dynamic magnification factors. As for the design purpose for railway turnout components, the maximum positive bending moments at rail seats and the maximum negative bending moment at mid span should be closely considered. It is thus important to note that the lowest bending mode (associated with the moderate pulse P2 due to rail dipped trajectories) plays a vital role on the dynamic bending moments at rail seats and at mid span as the dynamic magnification factor can rise up to over 2.50. In addition, the dynamic bending moments at outter rail seats could be affected largely by the third and fourth bending resonances (associated with the very short pulse P1 due to the wheel-rail transfer at a crossing nose). However, such P1 effect is relatively moderate. Future work will consider the effect of coupling dynamic wheel forces when both railseats are experiencing a variety of dynamic amplifiers.

ACKNOWLEDGMENTS

The first author wishes to gratefully acknowledge the Japan Society for Promotion of Science (JSPS) for his JSPS Invitation Research Fellowship (Long-term), Grant No L15701, at Track Dynamics Laboratory, Railway Technical Research Institute and at Concrete Laboratory, the University of Tokyo, Tokyo, Japan. The JSPS financially supports this work as part of the research project, entitled "Smart and reliable railway infrastructure". Special thanks also to the European Commission for H2020-MSCA-RISE Project No. 691135 "RISEN: Rail Infrastructure Systems Engineering Network" [34]. In addition, the sponsorships and assistance from CEMEX, Network Rail, RSSB (Rail Safety and Standard Board, UK) and G+D Computing (Dr Erik Kostson) with respect to STRAND7 are highly appreciated. The valuable comments from ISO/BSI Standard committee members for railway sleepers and bearers (especially Drs Makoto Ishida and Neil Gofton) are highly appreciated.

REFERENCES

[1] Standards Australia (2003), Australian Standard: AS1085.14-2003 Railway track material - Part 14: Prestressed concrete sleepers, Sydney, Australia.

[2] Kaewunruen, S., Ishida, T., Remennikov, A.M., (2015), "Numerical simulations of negative flexural responses (hogging) in railway prestressed concrete sleepers", RILEM International Conference on Strategies for Sustainable Concrete, Rio de Janeiro, Brazil, December 14-16, 2015.

[3] Kaewunruen, S., Ishida, T., Remennikov, A.M., (2016), "Impact analyses for

negative flexural responses (hogging) in railway prestressed concrete sleepers", International Conference on Recent Advances in Structural Dynamics, Southampton, UK, July 3-6, 2016.

[4] Kaewunruen, S., Minoura, S., Watanabe, T., Remennikov, A.M., (2016), "Remaining service life of railway prestressed concrete sleepers", Proceedings of International RILEM Conference on Materials, Systems and Structures in Civil Engineering, 22-24 August 2016, Technical University of Denmark, Lyngby, Denmark.

[5] Esveld, C., Modern Railway Track, 2nd Edition, MRT-Productions, Zaltbommel, The Netherlands. [http://www.esveld.com]

[6] Neilsen JCO. Eigenfrequencies and eigenmodes of beam structures on an elastic foundation, Journal of Sound and Vibration, 145 (1991), 479-487.

[7] Cai Z. Modelling of rail track dynamics and wheel/rail interaction, Ph.D. Thesis, Department of Civil Engineering, Queen's University, Ontario, Canada, 1992.

[8] Grassie, S.L. Dynamic modelling of concrete railway sleepers. Journal of Sound Vibration, 187, 799-813, 1995.

[9] Kaewunruen S, Remennikov AM. (2006) Sensitivity analysis of free vibration characteristics of an in-situ railway concrete sleeper to variations of rail pad parameters, Journal of Sound and Vibration 298(1): 453-461.

[10] Kaewunruen S, Remennikov AM. (2006) Rotational capacity of railway prestressed concrete sleeper under static hogging moment, the 10th East Asia-Pacific Conference on Structural Engineering and Construction, Bangkok, Thailand.

[11] Kaewunruen S, Remennikov AM. (2007) Investigation of free vibrations of voided concrete sleepers in railway track system, Journal of Rail and Rapid Transit – Proceedings of the Institution of Mechanical Engineers Part F Journal of Rail and Rapid Transit, 221(4): 495-507.

[12] Remennikov, A.M. and Kaewunruen, S., (2008). A review on loading conditions for railway track structures due to wheel and rail vertical interactions, Structural Control and Health Monitoring, 15(2): 207-234.

[13] Leong J. Development of limit states design concept for railway tracks, *Master of Engineering Thesis*, Queensland University of Technology, Brisbane, QLD, Australia, 2007.

[14] Wolf, H.E., J.R. Edwards, M.S. Dersch and C.P.L. Barkan. (2015) Flexural Analysis of Prestressed Concrete Monoblock Sleepers for Heavy-haul Applications: Methodologies and Sensitivity to Support Conditions. In: Proceedings of the 11th International Heavy Haul Association Conference, Perth, Australia, June.

[15] Sae Siew, J., Mirza, O., Kaewunruen, S., (2015), Nonlinear finite element modelling of railway turnout system considering bearer/sleeper-ballast interaction, Journal of Structures, http://dx.doi.org/10.1155/2015/598562

[16] Sae Siew, J., Mirza, O., Kaewunruen, S., (2017), Torsional effect on track support structures of rail turnouts crossing impact, ASCE Journal of Transportation Engineering, in press. doi: 10.1061/JTEPBS.0000004

[17] Vu, M., Kaewunruen, S., Attard, M., (2016), Chapter 6 – Nonlinear 3D finite-element modeling for structural failure analysis of concrete sleepers/bearers at

an urban turnout diamond, in Handbook of Materials Failure Analysis with Case Studies from the Chemicals, Concrete and Power Industries, p.123-160, Elsevier, the Netherlands. doi: 10.1016/B978-0-08-100116-5.00006-5

[18] Manalo, A., Aravinthan, T., Karunasena, W., Stevens, N., (2012), “Analysis of a typical railway turnout sleeper system using grillage beam analogy”, Finite Elements in Analysis and Design, 48(1): 1376-1391.

[19] Ferdous, W., Manalo, A., Van Erp, G., Aravinthan, T., Kaewunruen, S., Remennikov, A.M. (2015), “Composite railway sleepers – Recent developments, challenges and future prospects”, Composite Structures, 134(12): 158-168.

[20] Kaewunruen, S. (2012). Effectiveness of using elastomeric pads to mitigate impact vibration at an urban turnout crossing, in Maeda et al. (Eds.) Noise and Vibration Mitigation for Rail Transportation Systems, Springer, 357-365. doi: 10.1007/978-4-431-53927-8_42

[21] Kaewunruen, S. (2014). “Monitoring in-service performance of fibre-reinforced foamedurethane sleepers/bearers in railway urban turnout systems”, Structural Monitoring and Maintenance, 1(1): 131-157. doi: 10.12989/smm.2014.1.1.131

[22] Kassa, E. & Nielsen, J. C. O. (2009). Dynamic train–turnout interaction in an extended frequency range using a detailed model of track dynamics. Journal of Sound and Vibration, 320, 893-914.

[23] Wiest, M., Kassa, E., Daves, W., Nielsen, J. C. O. & Ossberger, H. (2008). Assessment of methods for calculating contact pressure in wheel-rail/switch contact. Wear, 265, 1439-1445.

[24] Xiao, J., Zhang, F. & Qian, L. (2011). Numerical simulation of stress and deformation in a railway crossing. Engineering Failure Analysis, 18, 2296-2304.

[25] Kaewunruen, S. and Remennikov, A.M. (2016). “Current state of practice in railway track vibration isolation: an Australian overview”, Australian Journal of Civil Engineering 14 (1), 63-71. doi: 10.1080/14488353.2015.1116364

[26] Kaewunruen S, Remennikov AM. (2007). Field trials for dynamic characteristics of railway track and its components using impact excitation technique, *NDT&E International*, 40: 510-519. doi: 10.1016/j.ndteint.2007.03.004

[27] Kaewunruen S, Remennikov AM. (2008). “Influence of ballast conditions on flexural responses of railway concrete sleepers in track systems”, Concrete In Australia, *Journal of Concrete Institute of Australia*, 35(4): 57-62.

[28] G+D Computing, Using Strand7: Introduction to the Strand7 finite element analysis system, Sydney, Australia, 2001.

[29] Sato M., Kanie S., and Mikami T. (2007) Structural modeling of beams on elastic foundations with elasticity couplings, *Mechanics Research Communications*, 34(5-6), 451-459.

[30] Shokrieh M.M. and Rahmat M., (2007). Effects of Young’s modulus on response of railway sleeper. Applied Mathematic Modelling, 31(4): (2007) 700-711.

[31] Kaewunruen, S. and Chamniprasart, K. (2016), “Damage analysis of spot replacement sleepers interspersed in ballasted railway tracks”, Proceedings of the 29th Nordic Conference on Computational Mechanics, Chalmers University of Technology, Gotenburg, Sweden.

[32] Samuels J.M., Palesano J.J. Using mainline wheel impact detectors to increase the productivity of car inspection functions, *Proceedings of Conference on Railway Engineering*, September 14-16, Perth, Australia, 1987.

[33] Kaewunruen, S., Remennikov, A.M., Dindar, S., (2017), "Influence of asymmetrical topology on structural behaviours of bearers and sleepers in turnout switches and crossings", In: Pombo J., Jing G. (eds) Recent Developments in Railway Track and Transportation Engineering. GeoMEast 2017. Sustainable Civil Infrastructures. Springer, Cham. doi: 10.1007/978-3-319-61627-8_4

[34] Kaewunruen, S,, Sussman, J.M. and Matsumoto, A. (2016) "Grand Challenges in Transportation and Transit Systems", Frontiers in Built Environment, 2:4. doi: 10.3389/fbuil.2016.00004

Corresponding author

Sakdirat Kaewunruen

Department of Civil Engineering, School of Engineering, The University of Birmingham, Birmingham B152TT UK

E-mail: s.kaewunruen@bham.ac.uk

Bio: A positive and self-motivated technical manager and specialist with extensive experience across civil, transport, and rail industry in public and private sectors. Expertise in transport infrastructure engineering and management, successfully dealing with all stages of infrastructure life cycle and assuring safety, reliability, resilience and sustainability of rail infrastructure systems. Highly skills in business management and continuous improvement of customer experience. Zac is a chartered engineer, has over 300 technical publications and held a visiting position in various institutions including Massachusetts Institute of Technology, Chalmers University of Technology, University of Illinois at Urbana Champaign, University of Tokyo, and Railway Technical Research Institute. Dr Kaewunruen has extensive experience in the field of structural, civil and railway track engineering both in industry and in academia. With over decades in industry and regulatory environments, he has wide variety of specialisations, including rail engineering, track engineering, track components, structural and geotechnical engineering, maintenance and construction. He has research and practical experience internationally in railway systems and infrastructure engineering. His work has involved many industry projects worth over £5billions and supervised/participated in railway research projects worth over £8millions (in Australia, UK, Japan, USA, Sweden, China, Malaysia and Thailand). He published significantly in this field in terms of both academic work and evidenced-based governmental/authoritative technical reports. He has membership in EU-Cost Actions: TU1404 (Towards the next generation of standards for service life of cement-based materials and structures), CA15125 (Designs for noise reducing materials and structures), CA15202 (Self-healing as preventive repair of concrete structures) and TU1409 (Mathematics for Industry Network). Zac is a member of ISO and BSI standard committees for railway sleepers and recycling of rolling stocks. He successfully coordinates EU-funded RISEN (www.risen2rail.eu). He is also a committee member of Concrete Society West Midlands and is Chief Editor of Frontiers in Transportation and Transit Systems.

Plain Language Summary

Railway infrastructures are exposed to aggressive actions by train and track interaction. The detrimental loading causes damages in the railway concrete bearers installed in switches and crossings. The wheel forces are often due to the wheel-rail transfer over the dipped trajectory at a crossing nose. It is often found that turnout bearers can crack and break. The ballast degradation then causes differential settlement and later aggravates impact forces acting on partial and unsupported sleepers and bearers. This paper investigates the dynamic performance of railway concrete bearers at crossing panel, taking into account the nonlinear tensionless nature of ballast support. A finite element model was established and calibrated using static and dynamic responses using past experimental results. In this paper, new phenomena due to topologic asymmetry on both sagging and hogging behaviours of crossing bearers are firstly highlighted. In addition, it is the first to demonstrate the effects of dynamic load impulses on the design consideration of turnout bearers in crossing panel. The outcome of this study will benefit the railway turnout design and maintenance criteria in order to improve train-turnout interaction and reduce maintenance costs.