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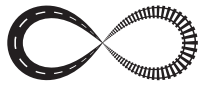
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## ASYMMETRICAL EFFECTS ON RAILWAY TURNOUT BEARERS DUE TO WHEELSET IMPACT OVER A CROSSING NOSE

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### Abstract

Railway infrastructure is a nonlinear complex system as witnessed by its actual behaviors, geometry and alignment, wheel-rail contact and operational parameters such as tractive efforts. It generally experiences harsh dynamic load conditions due to train-track interactions. In addition, ballast pressure and its degradation will cause differential settlement, resulting in further aggravated impact forces acting on partial and unsupported tracks. Especially at switch and crossing areas, the aggressive dynamic train-turnout interaction often damages the supporting components such as turnout bearers and fastening systems. This study presents a nonlinear finite element model of a standard-gauge concrete bearer in a turnout system, taking into account the nonlinear tensionless nature of ballast support. The finite element model was verified using static and dynamic measures from in laboratory and in the field. In this paper, the dynamic effects of topologic asymmetry on both dynamic sagging and hogging behaviours of sleepers under a wheelset's impulse loading are firstly highlighted. In addition, it is the first to demonstrate the dual-wheel effects of asymmetrical length on the nonlinear dynamic behaviour of the turnout bearers when the wheel running over the crossing nose. It would be naively thought that a failure of a single bearer or sleeper would not affect train operations; indeed, historical findings shows that such the failure at critical locations (e.g. at crossing panel, joints/welds, misaligned track, location with rail foot damage, and many more) could give rise to crossing nose damage, broken rail, broken joints, bowed baseplates, broken bolts, and so on. The outcome of this study is very critical to public safety and will improve the insight into structural damage and predictive condition-based track maintenance. It will help track engineers to appropriately adjust support profile and develop solution in order to mitigate excessive bearer/ballast interaction.

*Keywords: asymmetry, topology, nonlinear dynamics, railway bearers, railway turnout systems*

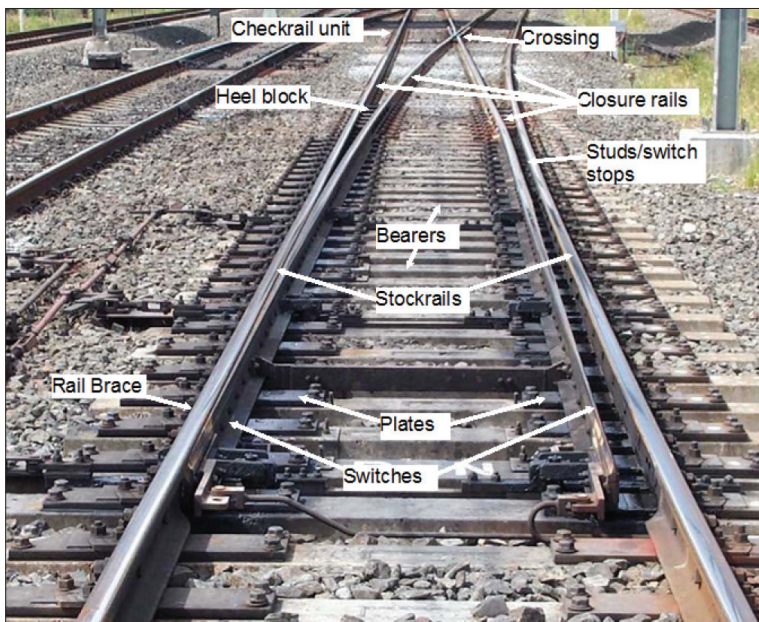
### 1 Introduction

A railway network can be comprised by many types of railway tracks and their components. In fact, even a railway line consists of many key infrastructure components that form specific functional assets such as railway tracks, bridges, turnouts (switches and crossings), overhead line structure, etc. A common type of railway infrastructure is ballasted railway tracks [1]. Railway sleepers or bearers (also called 'railroad tie' in North America) are a vital structural element in the railway track systems. Railway sleepers are different to bearers in terms of topology, location, utilization, steel rail components they support, and the dynamic load

condition they are subjected to. Their key role is quite similar to sleepers that they serve to redistribute loads from the rails to the underlying ballast bed, as well as to secure rails and crossings under live operations. The design and testing approaches for both sleepers and bearers are similar. Based on the current design approach, the design life span of the concrete sleepers is targeted at around 50 years in Australia [2] and around 70 years in Europe [3-6], whilst turnout bearers tend to last just about half lives of sleepers in the field [7-10].

## 1.1 Turnouts

Railway turnout or called ‘switch and crossing’ 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, steel plates, rubber pads, insulators, fasteners, screw spikes, beam bearers (either timber, polymer, steel or concrete), ballast and formation (see Figure 1). This complex system requires the track support to have structural integrity; and a broken bearer can significantly impair operational safety [11-15].

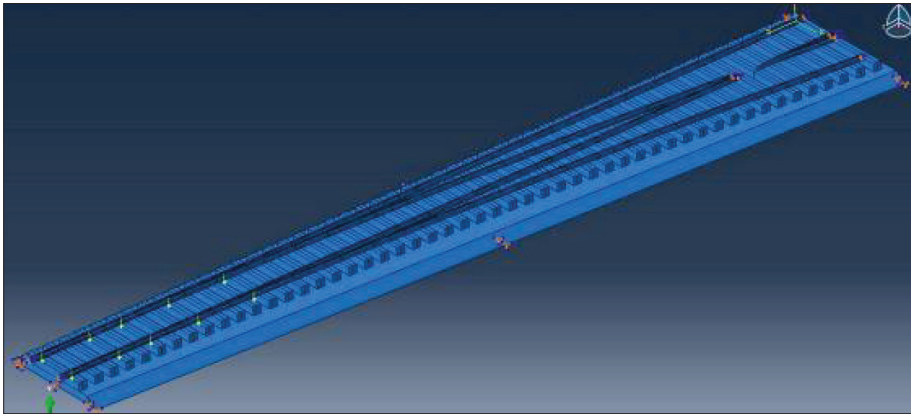


**Figure 1** A typical turnout structure with concrete bearers [5]

## 1.2 Previous studies

Thanks to continuous research and development on railway turnout systems, there have been a number of previous investigations on the railway sleeper and bearer models [16-20]. 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 [21-24]. In practice, the lateral force is less than 20% of vertical force and the anchorage of fastening has been designed to take care of lateral actions [25]. 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 [26-30]. 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 mid span, which is the cause of centre binding. 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).



**Figure 2** A typical turnout system layout [23, 24]

Based on a critical review of open literatures, the dynamic behavior of turnout bearers has not been fully investigated. As shown in Figure 2, a railway turnout system can generally be analysed the using a grillage beam method [27]. Although the simplification is very 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 [23]. A number of researches have 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 [24]. Although it is clear that the turnout bearers are topological asymmetry, such the aspect has never been fully investigated. This paper highlight a turnout bearer modeling capable of nonlinear impact analysis into the dynamic effect of topological asymmetry of railway turnout bearers. It focuses on the nonlinear dynamic flexural responses of railway concrete sleepers subjected to a spectrum of ballast stiffness at the mid span, in comparison with the current design method in accordance with the design standards [31]. Since dynamic impact loads are over a quarter of annual track load spectra, the dynamic behaviour is crucial to track maintenance criteria [32-33]. Therefore, the effect of wheelset dynamics over crossing nose (with an unbalanced single impact loading) will be focussed in this study.

## 2 Modelling

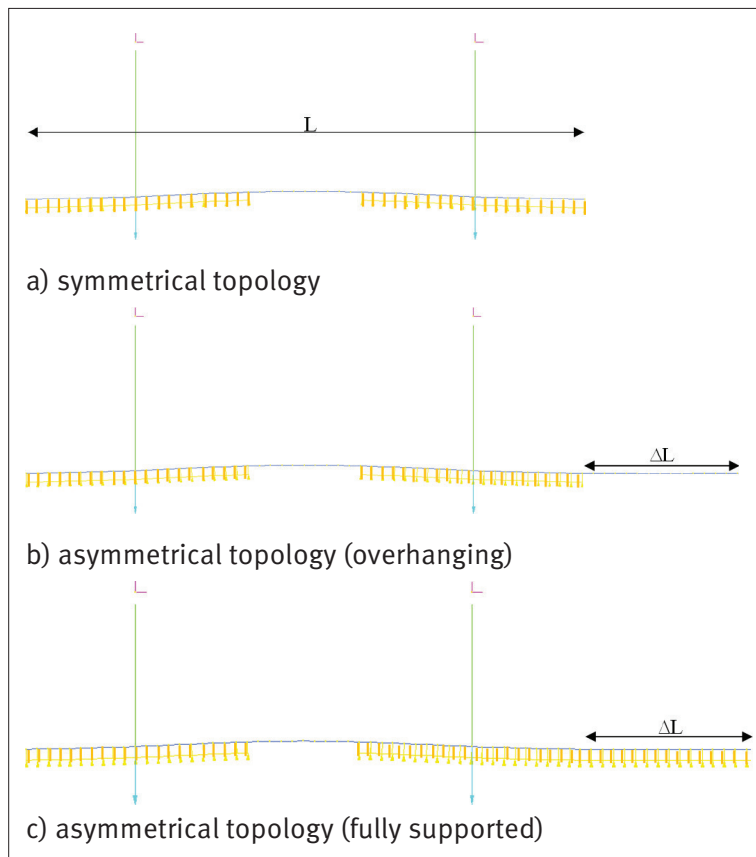
### 2.1 Computational Mechanics

In this study, a finite element model of concrete bearer has been previously developed and calibrated against the numerical and experimental modal parameters [22]. The model is in very good agreement with previous extensive studies, which established that the two-dimensional Timoshenko beam model is the most suitable option for modeling concrete sleepers under vertical loads [16-18]. Figure 3 shows the two-dimensional finite element model for in-situ railway turnout bearers. Using STRAND7 [34], the numerical model included the beam elements, which take into account shear and flexural deformations. 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 bearer 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. The use of elastic foundation in the current standards in Australia and North America does not well represent the real uplift behaviour of bearers in hogging moment region (or mid span zone of railway bearers). In this study, the support condition was simulated using the tensionless beam support feature in STRAND7 [34]. This attribute allows the beam to lift or hover over the support while the tensile supporting stiffness is omitted. The tensionless support can correctly represent the real tracks.

## 2.2 Parametric Analyses

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 in Europe. These data have been validated and the verification results have been presented elsewhere [28]. Also, 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 sleeper has not yet addressed by the past researchers. Especially when the uplift behaviour due to ballast 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 simulations have been extended to conduct the analyses using the nonlinear solver in STRAND7. The effects of asymmetric topology of concrete bearers on their flexural responses can be evaluated. The length of bearer varies from 2.5 m to 4.0 m, which is practically common in the 2 and 3 rail-seats sections (see Figure 3). The impulse is stimulated only at the inner rail seat (as the inner wheel travels over crossing).



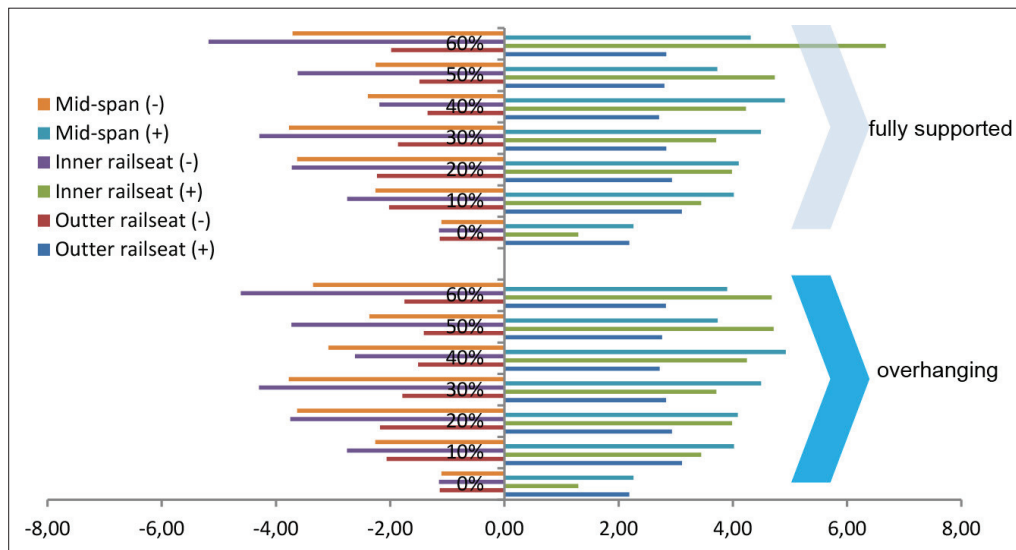
**Figure 3** STRAND7 finite element model of a concrete bearer

**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 <sup>2</sup>
Shear rigidity	$\kappa GA_c = 502, \kappa GA_r = 628$	MN
Ballast modulus	$k_b = 13$	MN/m <sup>2</sup>
Rail pad stiffness	$k_p = 17$	MN/m
Sleeper density	$\rho_s = 2,750$	kg/m <sup>3</sup>
Sleeper length	$L = 2.5$	m
Track load distance	$g = 1.5$	m

### 3 Results and Discussion

Using data in Table 1, Figure 4 shows dynamic bending moment envelops along the bearer when subjected to the wheel load impulse of 100 kN (3 ms) at a railseats. Damping of concrete is relatively low and is neglected in this study. Based on AS1085.14 [2], the design maximum positive and negative bending moment at the rail seat is 12.50 kNm (if considered full support).



**Figure 4** Dynamic moment ratio ( $M_{dynamic}/M_{design}$ ) vs. vertical axis  $\Delta L/L$

The results shows that the wheel impact loading can cause high impact factor over 2.5 and some cases can be over 4.0 in both conditions. These exceed the design limits for fatigue serviceability and ultimate limit states, respectively.

### 4 Conclusion

In railway switches and crossings, turnout bearers are structural and safety critical components. This paper identifies the critical dynamic transient effects of ballast conditions, asymmetric topology, and wheelset impact on the flexural responses of railway turnout bearers in a turnout system. The results clearly show that the impact load can amplify the bending moments in both conditions, resulting in potential damages under high-intensity impact loading, which could trigger and sweep through various resonant frequencies of the turnout bearers. The understanding has raised the awareness of track engineers for better design and maintenance of turnout support structures to minimise transient effects.

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