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DYNAMIC AMPLIFICATION FACTORS FOR RAILWAY TURNOUT BEARERS IN SWITCHES AND CROSSINGS

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Abstract. *Railway infrastructure is nonlinear by nature, scientifically proven by its behaviours, geometry and alignment, wheel-rail forces and operational parameters such as tractive efforts. It is often found that most train-turnout interaction models do not consider the time dependent ballast degradation. Such ballast degradation later causes differential settlement and aggravates impact forces acting on partial and unsupported sleepers and bearers. Furthermore, localised ballast breakages underneath any railseat increase the likelihood of centre-bound cracks in railway sleepers and bearers due to the unbalanced support. This paper presents a numerical simulation of a standard-gauge concrete bearer at crossing panel, taking into account the tensionless nature of ballast support. The finite element model was calibrated using static and dynamic responses using past experiments. In this paper, the influences of topologic asymmetry on dynamic amplification behaviours of crossing bearers under impact loading are firstly investigated. In addition, it is the first to demonstrate the effects of sleeper length on the design consideration of turnout bearers in crossing panel. The outcome of this study will improve the railway turnout construction and maintenance criteria in order to improve train-turnout interaction and ride comfort.*

1 INTRODUCTION

A typical ballasted railway track consists of many key components that form specific functional assets such as railway tracks, bridges, turnouts, overhead line structure, etc. 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. Based on the current design approach, the design life span of the concrete sleepers is targeted at around 50 years in Australia and around 70 years in Europe [1-6], whilst turnout bearers tend to last just about half lives of sleepers in the field. There have been a number of previous investigations on the railway sleeper/bearer models [7-11]. 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 [12-14]. 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 [12]. 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 [13-18]. 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 bound. 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).

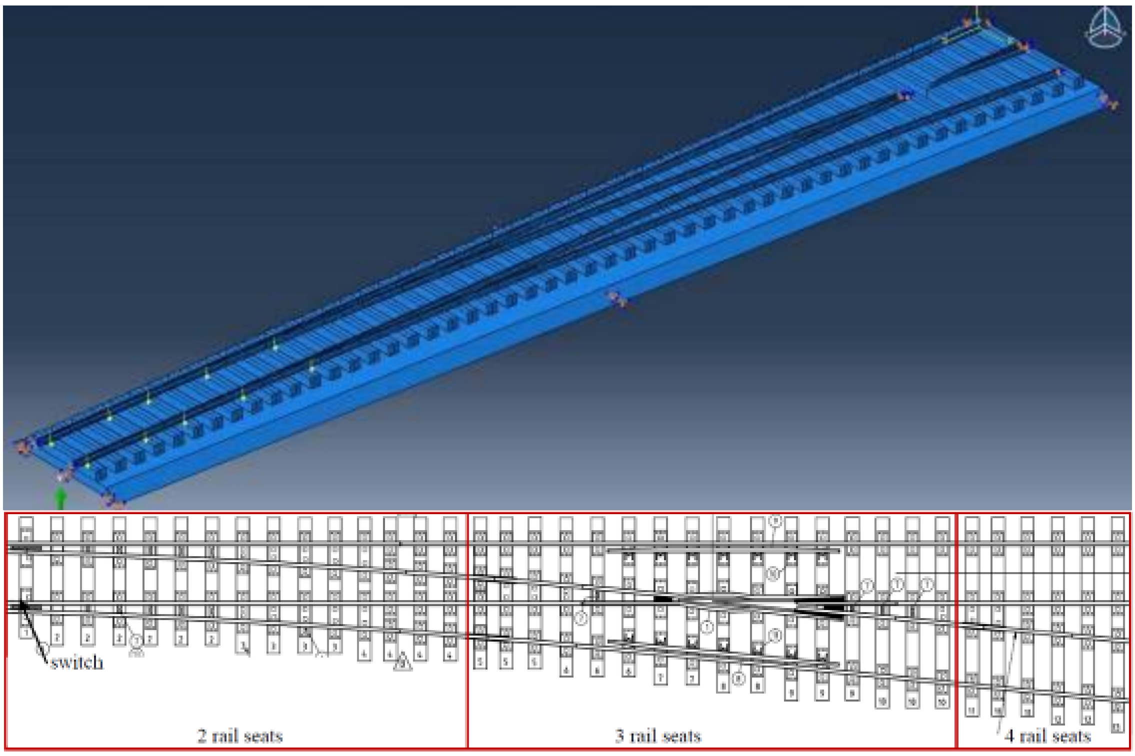

Figure 1: Typical turnout system layout (Sae Siew et al., 2016).

Based on a review of open literatures, the dynamic behavior of turnout bearers has not been fully investigated. As shown in Figure 1, a railway turnout system have generally been analysed the using a grillage beam method [19-20]. 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 [21]. 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 [20]. Although it is clear that the turnout bearers are topological asymmetry, such the aspect has never been fully investigated. This paper presents an advanced 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.

2 FINITE ELEMENT MODEL

In this study, a finite element model of concrete sleeper (optimal length) has been previously developed and calibrated against the numerical and experimental modal parameters [15]. 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 [7-9]. Figure 2 shows the two-dimensional finite element model for in-situ railway turnout bearers. Using a general-purpose finite element package STRAND7 [22], 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 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. It is noted that the use of elastic foundation in the current standards in Australia and North America [1, 18] 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 [22]. 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. 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 [15]. 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 [21]. 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 numerical 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 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 Figure 2).

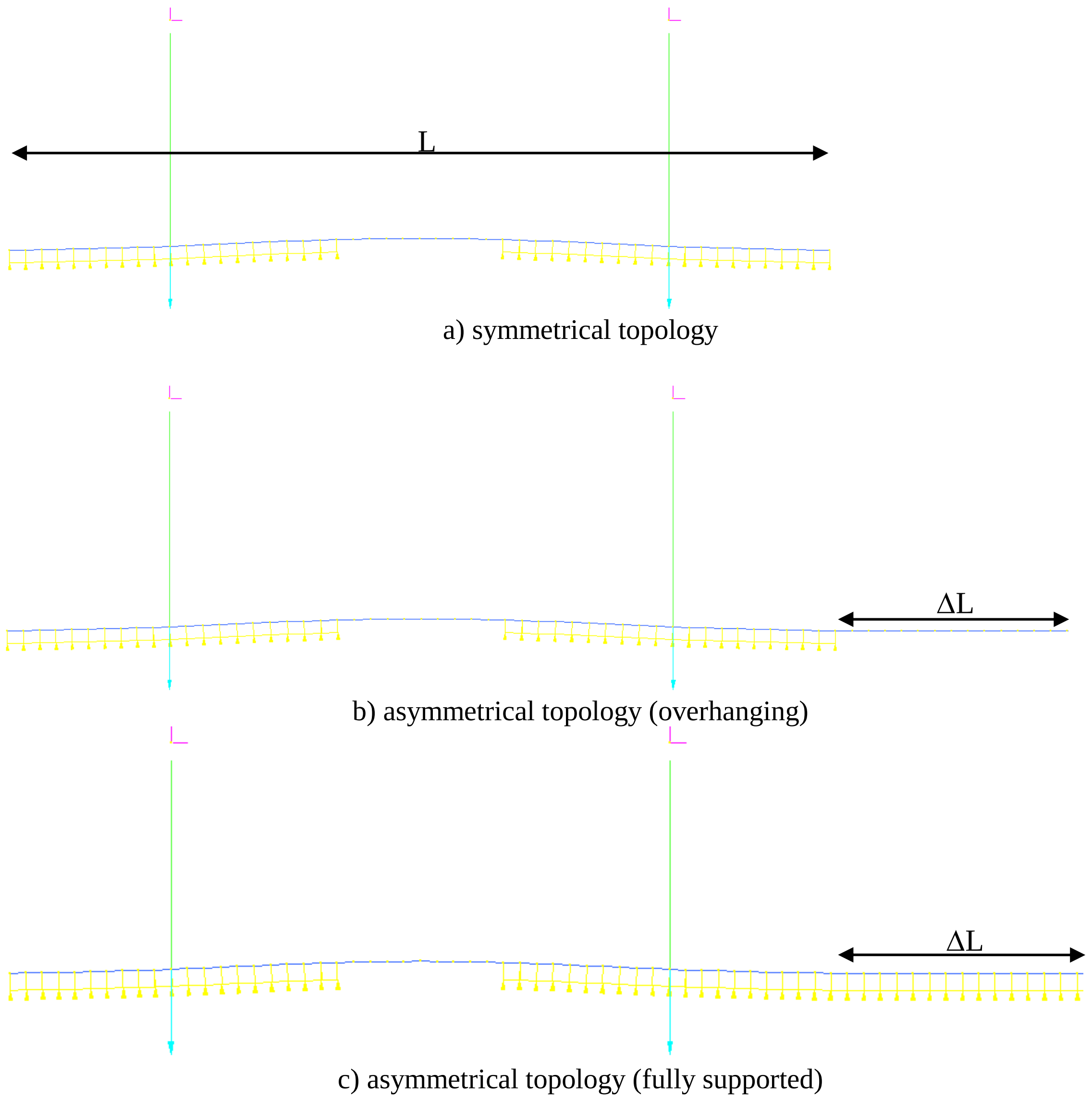

Figure 2. STRAND7 finite element model of a concrete bearer

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^2
Shear rigidity	$\kappa GA_c = 502$, $\kappa GA_r = 628$	MN
Ballast stiffness	$k_b = 13$	MN/m^2
Rail pad stiffness	$k_p = 17$	MN/m
Sleeper density	$\rho_s = 2{,}750$	kg/m^3
Sleeper length	$L = 2.5$	m
Rail gauge	$g = 1.5$	m

3 RESULTS AND DISCUSSION

The numerical simulations based on the design data in Table 1 enable Tables 2 and 3 that present the dynamic bending moment envelops along the bearer when subjected to the equal wheel load impulse of 100kN (3 ms) at both railseats, in comparison with the standard design moments. Based on AS1085.14 (Standards Australia, 2003), 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.

Table 2 Maximum bending moment of overhanging bearer

ΔL/L	**At railseat (kNm)**		**At mid span (kNm)**	
(overhanging)	M*	$\lvert M^*/M_{Design}\rvert$	M*	$\lvert M^*/M_{Design}\rvert$
0	+ 13.81	1.1048	+15.01	2.16
10%	+14.40	1.152	- 8.01	1.15
20%	+18.65	1.492	+9.30	1.34
30%	+14.46	1.1568	+16.14	2.32
40%	+13.29	1.0632	+14.34	2.06
50%	+14.69	1.1752	+12.08	1.74
60%	+14.17	1.1336	+10.09	1.45

Table 3 Maximum bending moment of fully-supported bearer

ΔL/L	**At railseat (kNm)**		**At mid span (kNm)**	
(full support)	M*	$\lvert M^*/M_{Design}\rvert$	M*	$\lvert M^*/M_{Design}\rvert$
0	+ 13.81	1.10	+15.01	2.16
10%	+14.40	1.15	+9.35	1.35
20%	+18.69	1.50	+9.50	1.37
30%	+14.51	1.16	+16.50	2.37
40%	+13.30	1.06	+14.85	2.14
50%	+14.73	1.18	+12.75	1.83
60%	+14.21	1.14	+10.00	1.44

Based on the static results in Tables 2 and 3, it is clear that the influence of the asymmetrical topology is more pronounced when there is a contact between bearer and ballast layer. Considering field investigation, such the contact could occur when there is a differential settlement on the mainline track (or run-through turnout road). Once the ballast-bearer contact establishes, the bearer will take additional bending moment at the inner railseat. Figures 3 and 4 demonstrate the dynamic amplification factors (DAF) for the turnout bearers. It can be seen that the common use of DAF around 2.5 (e.g. in Australian Standard and AREMA) is considered to be suitable for the turnout bearers, provided that the dynamic impact load amplitudes are retained at the same level. This also implies that if the train wheels or turnout crossings are not properly maintained, the turnout bearers are likely to reach the structural capacity design under dynamic loading and are potentially be damaged.

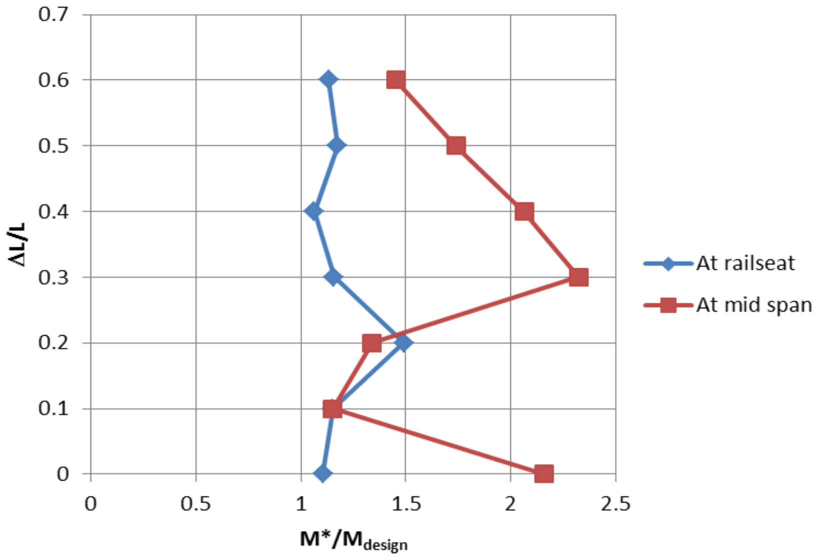

Figure 3. Dynamic amplification factor of concrete bearers under overhanging condition

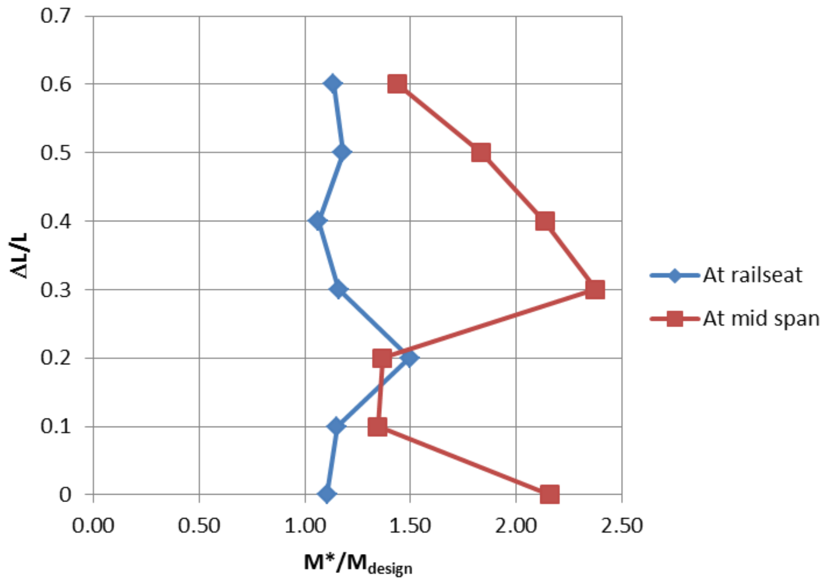

Figure4. Dynamic amplification factor of concrete bearers under ballast support condition

4 CONCLUSION

Railway turnout bearers are structural and safety critical components in railway turnout systems. This paper evaluates the critical dynamic transient effects of a variety of ballast conditions and asymmetric topology on the flexural responses of railway turnout bearers in a turnout system (switches and crossings) subjected to impact loading. The finite element model of bearers, which was established and calibrated earlier, is utilised in this study. The nonlinear solver in STRAND7 was employed to handle sleeper/ballast contact mechanics. Under dynamic impact conditions for overhanging and supported bearers, the numerical results exhibit that the bending moment resultants are considerably affected by topological aspects, especially when the ballast-sleeper contact is established. The standard design bending moments tend to be a fair estimate for both supported and overhanging conditions. 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. By understanding the impact behavior of turnout bearers, it is clear that the dynamic amplification factor of 2.5 is a minimum requirement in the design of turnout bearers. This implies that the turnout 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 this dynamic behavior of bearer has raised the awareness of track engineers for better design and maintenance of switch and crossing support structures.

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