ASYMETRICAL INFLUENCES ON NONLINEAR DYNAMICS OF RAILWAY TURNOUT BEARERS

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By nature, railway infrastructure is nonlinear, evidenced by its behaviors, geometry and alignment, wheel-rail contact and operational parameters such as tractive efforts. It is noted that most train-track interaction models do not consider appropriate behaviour of ballast over time. In fact, the ballast degradation causes differential settlement and 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 paper presents a nonlinear finite element model of a standard-gauge concrete bearer in a turnout system, taking into account the tensionless nature of ballast support. The finite element model was calibrated using static and dynamic responses in the past. In this paper, the influences of topologic asymmetry on both dynamic sagging and hogging behaviours of sleepers under impulse loading are firstly highlighted. In addition, it is the first to demonstrate the effects of asymmetrical length on the nonlinear dynamic behaviour of the turnout bearers. The outcome of this study will improve the rail construction criteria in order to adjust support profile and appropriately mitigate bearer/ballast interaction. It will help improve the structural health monitoring strategy, enriching an intelligent track system.

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

1. Introduction

Globally, rail asset operators are considerably demanded by the public and other stakeholders to be more efficient than ever. It is thus important to enhance the maximisation of utilisation and flexibility of rail network, which is considered as one of the key strategies in rail asset management. A railway turnout is a critical part of the railway system where a track crosses over one another at an angle to divert a train from the original track. It allows for train vehicles to cross over or switch between various tracks, and in-turn maximising the utility of tracks and assets. Its main components include rails, switches, crossings, sleeper plates, sleepers, ballast and subgrade. The railway turnouts are an essential part of a rail system but at the same time, they are a costly feature to a rail system as they suffer adverse operational loads, in comparison to a plain rail track, and require regular maintenance [1-5].

Due to the particular geometry of wheel–rail contact and sudden variation of track flexibility, severe impact loads may occur during train passage over the turnout. Turnout components are subjected to general wear, rolling contact fatigue and accumulated irreversible (plastic) deformations [6-12]. Especially at turnouts crossing, the wheel rail interaction at the transfer zone often causes detrimental impact forces and excessive dynamic actions. Many studies showed that it is very likely that a railroad turnout bearers or crossties could be subjected to severe impact loads, resulting in a rapid deterioration in terms of structural integrity and durability, track settlement, and ride comfort [13-20].

In contrast, the structural behavior of turnout bearers has not been fully investigated. Figure 1 shows the typical layout of a turnout system [21]. A railway turnout system have generally been analysed the using a grillage beam method [22]. 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 [23]. 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 [24-25].

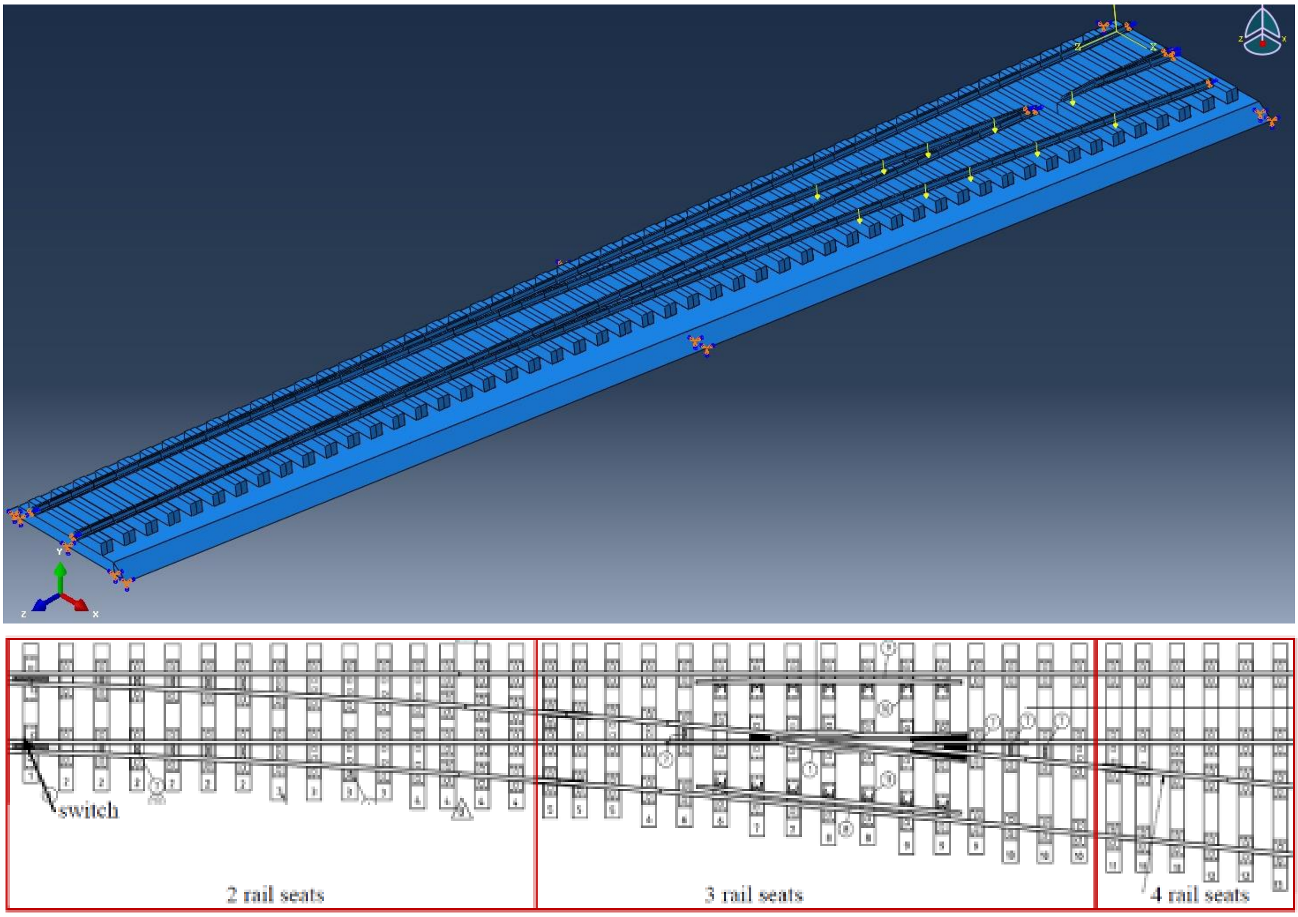

Figure 1: Typical turnout system layout

Based on the design, topological asymmetry has been implemented to enhance switches and crossing components. However, the asymmetrical influences on dynamic behaviour of turnout bearers have never been fully investigated. This paper presents a railway concrete sleeper modelling, which can take into account the topological asymmetry and ballast nonlinearity. The parametric study has been carried out to demonstrate the nonlinear dynamics of the turnout bearers in track systems.

2. Finite Element Analysis

Many researchers have found that the two-dimensional Timoshenko beam model is the most suitable option for modeling concrete sleepers under vertical loads [26-28]. To investigate the nonlinear dynamics, the finite element model of concrete bearer, which was previously developed and calibrated against the numerical and experimental modal parameters [28], has been adopted in this study. Figure 2 shows the two-dimensional finite element model for an in-situ railway concrete bearer. Using a general-purpose finite element package STRAND7 [19], 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 bearer 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 [28]. The validation has been carried out using modal finite model updating [16-17]. The experimental and numerical data is in good agreement with less than 5% difference.

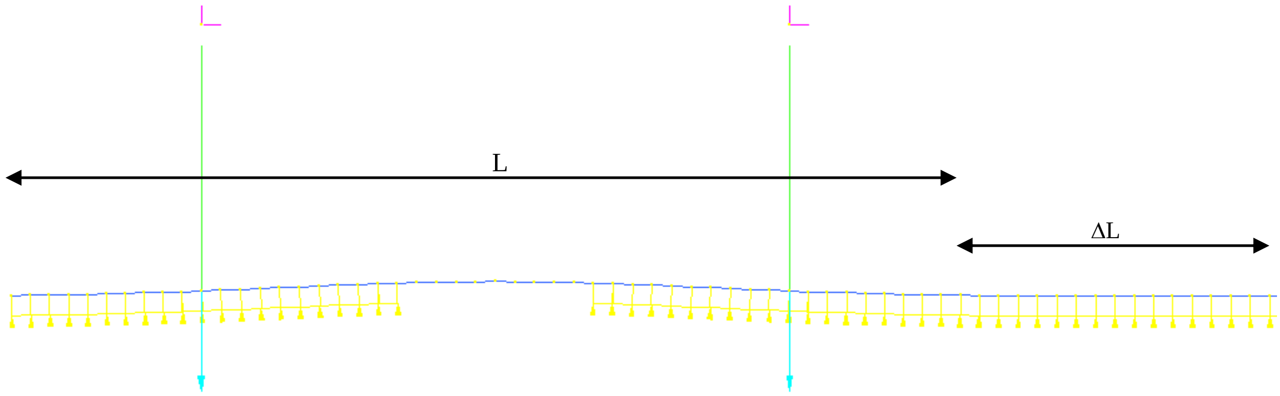

Figure 2: STRAND7 finite element model of railway turnout bearer.

In this study, the support condition was simulated using the tensionless beam support feature in Strand7 [19]. 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 [19]. 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 results have been presented [28].

Table 1: Engineering properties of the reference sleeper used in the modelling validation

Parameter List	Characteristic value	Unit
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-centre distance	$G = 1.5$	m
Rail gauge	$g = 1.435$	m

3. Simulation Results

Numerical simulations have been carried out to identify nonlinear dynamics of the turnout bearers. In this investigation, frequency analysis and impulse response have been discussed.

3.1 Nonlinear Dynamics

Figure 3 portrays the nonlinear softening phenomena of railway turnout bearers. Based on free vibration analysis, it can be observed that higher order modes are susceptible to the change in asymmetrical length of the bearers. The increment of asymmetry also induces dynamic softening behaviour of the bearers.

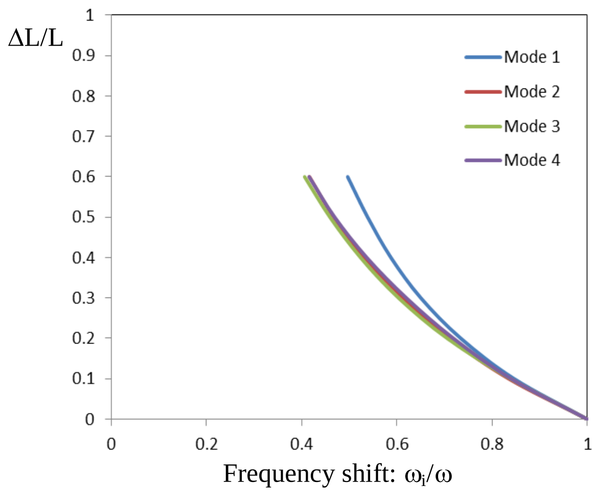

Figure 2: Nonlinear frequency change.

3.2 Impulse Responses

It is found that turnout bearers are subjected to impact loading, resulting in poor ride comfort [29] and environmental effects [30-32]. Figure 3 illustrates the impact responses of the turnout bearers under 5msec sinusoidal pulse. It can be seen that the dynamic bending moments at railseat (both sagging and hogging) exceeds the normal condition. This insight suggests that the bearers be designed using higher dynamic amplification factors in order to assure that they will not fail under services.

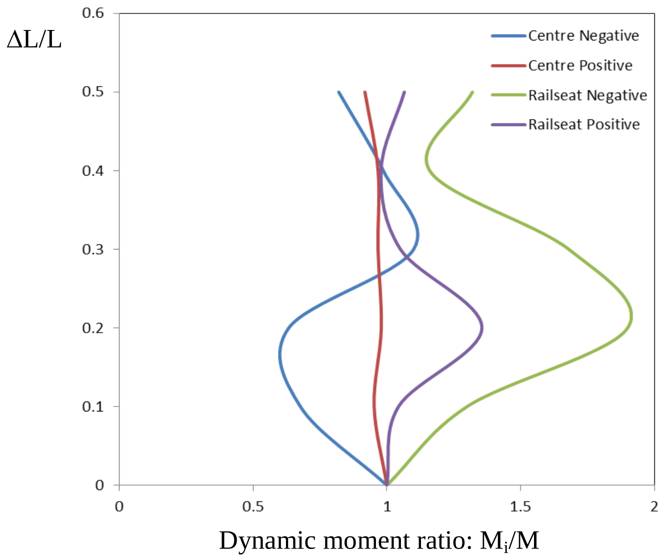

Figure 3: Dynamic bending responses of railway turnout bearer.

4. Conclusion

Railway turnouts are a critical railway infrastructure, which is complex and nonlinear. The turnout often experiences high intensity impact loading. At present, most train-track interaction models do not consider the degradation of ballast over time. Frequently, the ballast degradation causes differential settlement and aggravates impact forces acting on turnout systems. 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 paper presents a nonlinear finite element model of a standard-gauge concrete bearer in a turnout system, taking into account the tensionless nature of ballast support. The finite element model was calibrated using static and dynamic responses in the past.

Based on the frequency analysis, the topologic asymmetry induces dynamic softening nonlinearity on the turnout bearers. In addition, it can be observed that the railseat area is prone to be damaged under dynamic loading. The outcome of this study shows that the bearers should not be tamped throughout as the support profile increases dynamic interaction between bearer and ballast. The excessive interaction can cause rapid degradation of turnout components. The results also show that monitoring sensors should be placed at the inner railseats to monitor structural health conditions, enriching an intelligent track system.

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