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NONLINEAR MODELLING AND ANALYSIS OF MOVING TRAIN LOADS ON INTERSPERSED RAILWAY TRACKS

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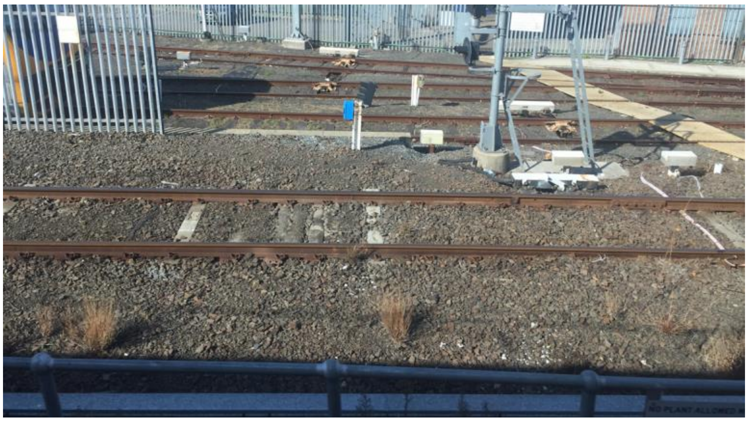
Abstract. *The interspersed pattern sleeper of railway track, which is a replacement of old timber sleeper with concrete, is often used as a temporary maintenance for second or third class railway lines with aging timber sleepers. However, their negative effect on the railway has to be taken into an account. The numerical simulations of interspersed sleeper railway tracks are conducted as well as the plain ones using a finite element program, STRAND7, so that the precise numerical models can be established. Two moving point loads, 100 kN each, are simulated to represent a passenger train bogie moving along each rail in 2 dimensional plane. Dynamic displacements and accelerations of all sleepers are then evaluated. Sensitivity analyses are carried out by varying the speed of the moving train loads from 5 km/h to 120 km/h and by changing the type of the interspersed patterns to determine the dynamic behaviours that can cause any more rapid deterioration of the interspersed tracks compared with plain railway tracks. The results demonstrate the potential sources of structural vibrations that will swiftly degrade the interspersed railway tracks. The insight will help track engineers to plan predictive maintenance and inspection of the interspersed railway tracks in live operational networks.*

1 INTRODUCTION

Timber components have for a long time been used as railway sleepers for a railway track in many parts of railway networks around the world. As the timber sleeper life span is around 15-20 years depending on application and maintenance, such timber sleepers will be required for maintenance or even a huge replacement at certain point in time. Also, unless used in low speed operation, timber sleepers require a strengthening for enhancement in ability to withstand high velocity operations or to restrain longitudinal rail forces preventing a track buckling. "Interspersed" is a method that can be used as a measure against these problems. Interspersed railway track can be built by re-sleepering old and rotten timber sleepers and replace it with concrete sleepers [1]. Due to differential track stiffness, deterioration process, and operational parameter, many patterns of interspersed railway tracks have been introduced i.e. 1 in 2, 1 in 3, 1 in 4 and so on (which mean there is 1 concrete sleeper in every indicated number of sleeper such as 1 in 4 mean 1 concrete sleeper in every 4 sleepers including the concrete itself). It is important to note that this type of railway track mainly existed in a second or third class of railway tracks with low operational speeds.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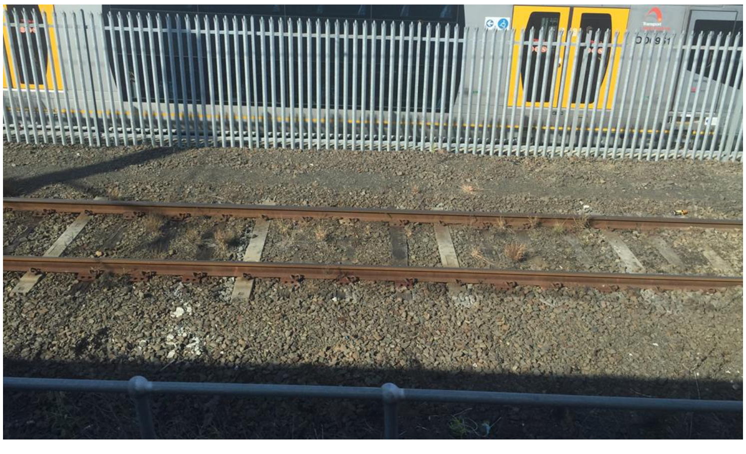
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Figure 1: Deteriorated interspersed railway track (Top: mud pumping, and Bottom: ballast pulverisation and ballast dilation)

The key reason is that this type of track has various flaws derived from how it is built. The replacement of old timber sleepers is frequently done over old and soft existed formation, which has been in services for so long, by installing new stiff concrete sleepers in its existing place. This can result in soil foundation failure, track stiffness inconsistency (as it made up of both concrete and timber sleepers), and differential track decay rate [2]. These can impair the long-term performance of interspersed railway tracks as shown in Figure 1. Figure 1 shows the conditions of interspersed railway tracks under low-speed operations (<25 km/h). The tracks have been commissioned between 2006 and 2008 and have served as a link to maintenance junctions. The photos were taken in April 2016 during a site visit.

The serviceability limit state (or dynamic performance) has become the governing criteria for sleepers made of different material properties in the existing aged track systems. Note that this method is sometimes called ‘spot replacement’ or ‘intersperse method’. It is important to note that a general recommendation (e.g. by Australian Office of Transport Safety Investigations) is to perform concrete sleeper installation only ‘in-face’ (i.e. the practice of installing the same sleeper type constinuously rather than interspersed with other sleepers in between, also referred to as ‘on-face’) [3-4]. This paper aims at investigating the nonlinear dynamic behaviours of the interspersed railway tracks. Based on critical literature review, this research has never been presented in open literature [3-6]. The insight into this practice will help rail track engineers to enable truly predictive track maintenance, enhance smarter track inspection regimes, and improve reliability of infrastructure assets in uncertain settings.

2 NONLINEAR FINITE ELEMENT MODELING

A 2D Timoshenko beam is selected as a beam model because it was found to be one of the most suitable options for modelling concrete sleeper [5]. For both rail track and sleeper they were designed as a beam element in finite model so shear and flexural deformation can be included in computation [6]. The rail pads at the rail seat are simulated by using series of spring dash-pot elements. In order to replicate ballast supports, non-linear tensionless beam support is used. The tensionless support can correctly demonstrate ballast under the sleeper as this attribute allow beam to lift over the support while the tensile support is omitted [6-8]. For train on the rail track, it is simplified to 2 points loads with 100kN in magnitude, 2m apart, on each side of the rail track (4 point loads in total), to enable envelop analysis (maximum responses). Figure 2 shows the illustration of the model.

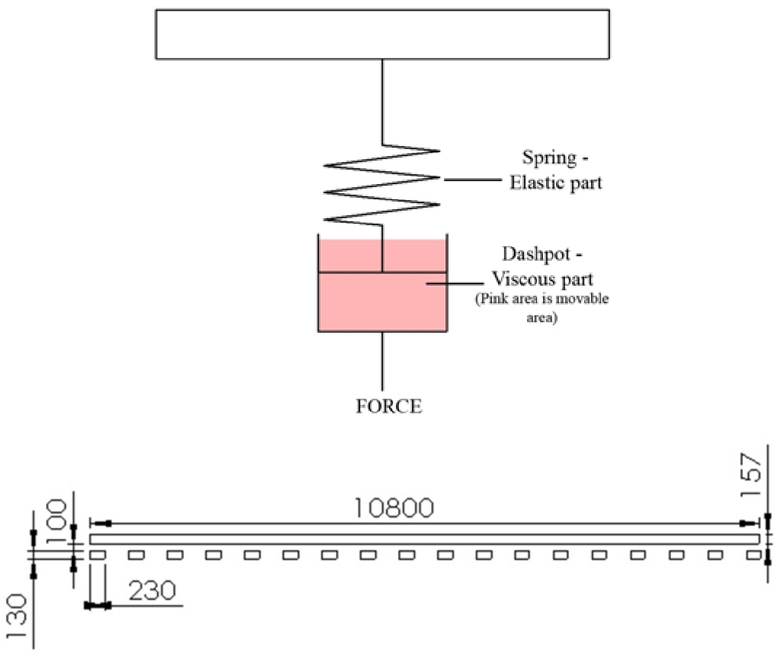

Figure 2: Schemetics of interspersed railway track modelling

The numerical simulation is conducted using non-linear transient dynamic solver in Strand7 to enable tensionless capability of ballast. The nonlinear iteration (Newton Raphson) has been used to compute the ballast contact and support. The model has been validated earlier using experimental parameters, field data and previous laboratory results [9-15].

3 DYNAMIC MOVING LOAD ANALYSIS

The effects of train velocity on the maximum responses of sleepers can be seen in Figure 3. The train speeds from 5 to 120 km/h have been investigated as shown in Figures 4 and 5. It is clear than the timber track has higher deformation. At rail seat, the relative uplifts of the sleepers tend to cause deteriorations of railway tracks over time. Figure 4 demonstrates the dynamic effects of interspersing methods coupled with train speeds on the maximum displacement responses of sleepers at mid spad. Considering the sleepers' responses, it is clear that timber sleepered tracks deform vertically lower than interspersed or concrete sleepered tracks. However, the concrete sleepers in either plain or interspersed tracks tend to deform significantly at their mid span. Such the deformations can cause centerbound problems or the issue with cracks at the midspan of sleepers. This issue is commonly found in railway tracks with poor maintenance. On this gound, the use of interspersed system will accelerate the centerbound problems in railway lines.

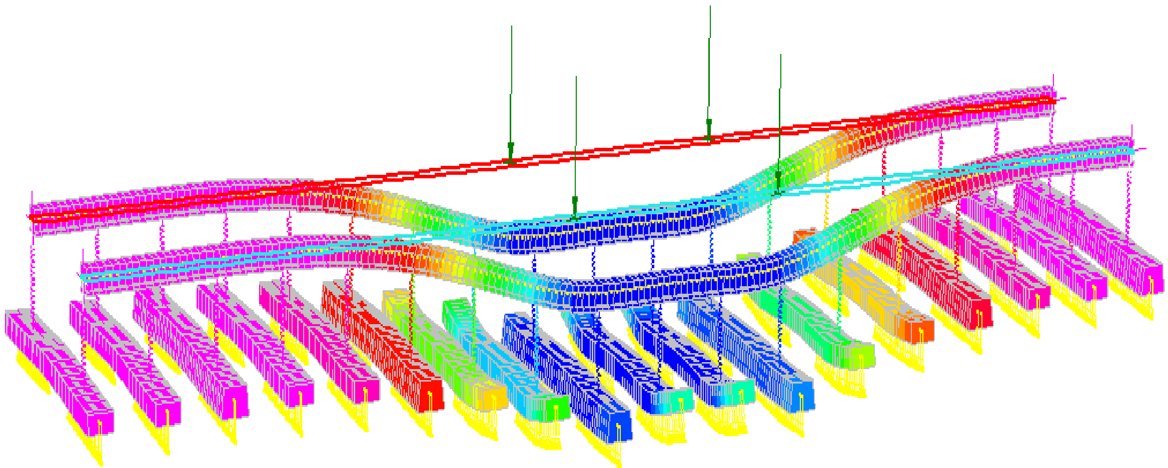

Figure 3: Dynamic responses of sleepers in the interspersed tracks

The dynamic effects of train velocity on the maximum uplift responses of sleepers can be seen in Figure 5. It is clear than the interspersed tracks have higher uplift deformation. The relative uplifts of the sleepers tend to cause deteriorations of railway tracks over time, such as ballast breakage, excessive dilation and densification, which can cause further track differential settlements. Figure 6 demonstrates the dynamic impact factor of interspersing methods coupled with train speeds on the maximum acceleration responses of the interspersed tracks. It is very clear that the heavy mass of concrete sleepers can suppress nonlinear vibration responses and secure the track through vibration control.

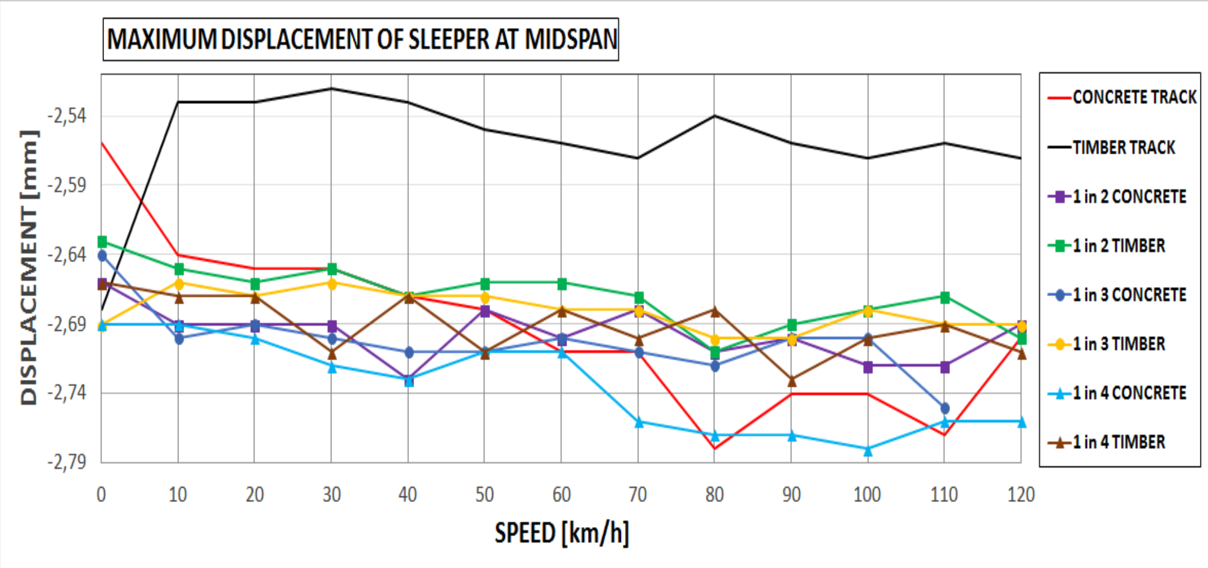

Figure 4: Maximum displacement of sleeper at midspan

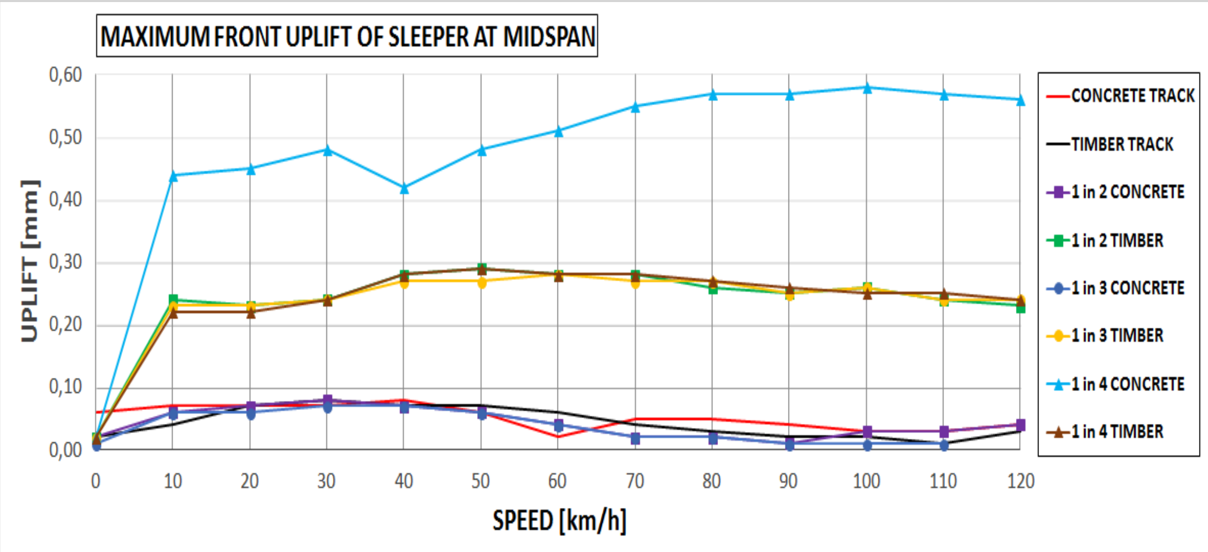

Figure 5: Maximum front uplift of sleeper at midspan

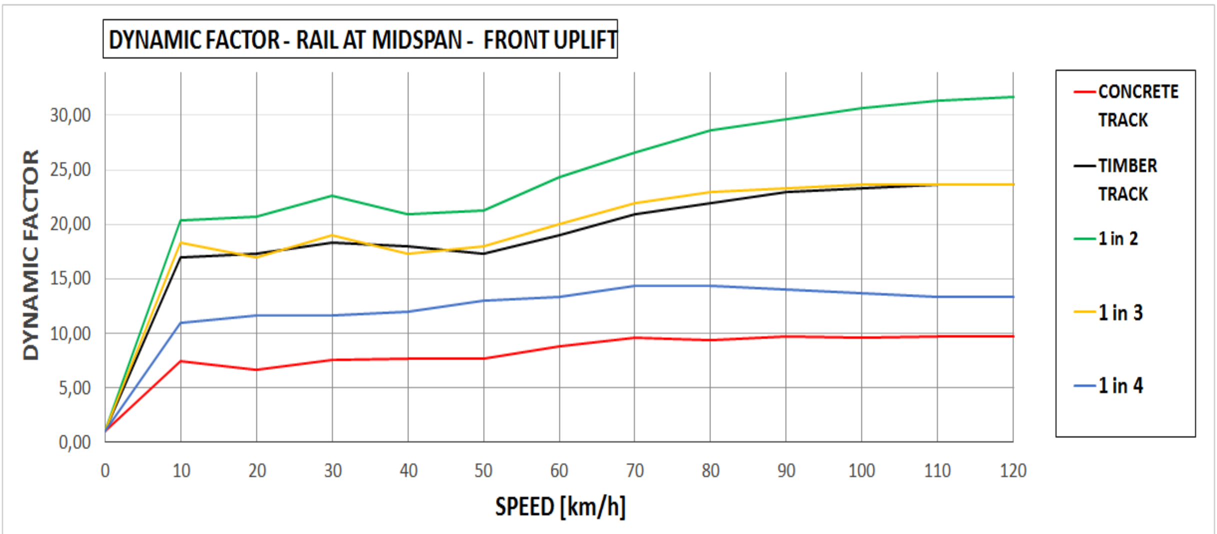

Figure 6: Dynamic factor of rail vibration at midspan (front uplift)

4 CONCLUSION

Railway industry in many countries around the world still adopts interspersed track system as a measure for spot replacement of decayed timber sleepers. Such practice is common for secondary or third class tracks where operations are not excessive. However, the practices can cause excessive track maintenance over time. This is because a cluster of timber sleepers with mixed quality could deteriorate faster than the others and the replacement by concrete sleepers could induce track stiffness inconsistency and aggravate loading conditions acting on the track. This paper is found to be the first to investigate nonlinear behaviours of the interspersed track due to a moving train load in order to understand the root cause of rapid track deterioration. A finite track models in three-dimensional space have been established and validated. The parametric studies have revealed the key insights into the actual source of track deterioration:

- Spot replacement of sleepers or interspersed tracks can deteriorate relatively faster than open-face tracks (i.e. pure concrete or timber sleepers). This is also evidenced by field monitoring.
- The cause of rapid deterioration such as track mud pumping, ballast pulverisation and ballast dilation is due to relative dynamic uplift responses of sleepers.
- Ballast dilation can be aggravated by concrete sleeper vibrations at resonance. The excessive ballast dilation can reduce lateral track stability.

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