Systemic values of enhanced dynamic damping in concrete sleepers – Comments on the paper

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Letter to the Editor

Systemic values of enhanced dynamic damping in concrete sleepers– Comments on the paper: Ahn S, Kwon S, Hwang Y-T, Koh H-I, Kim H-S, Park J. Complex structured polymer concrete sleeper for rolling noise reduction of high-speed train system, Composite Structures, 2019, 223:110944 (doi 10.1016/j.compstruct.2019.110944).

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Ahn et al [1] proposed an innovative polymer concrete sleeper for reducing rolling noise of high-speed train systems. The internal structure design of high damping concrete sleepers was conducted by installing polymer concrete to cement concrete sleepers. By mixing polymer and cement concrete, the damping performance of the meta-structure of sleepers was improved. However, the authors evaluated the proposed concept by the rolling noise modelling of slab tracks. Such the application was not well justified in the paper since the rolling noise frequency spectra often appear at a relatively low frequency range [2, 3]. Note that the most noise issues related to high speed rail systems tend to associate with high frequency noises such as aerodynamics, curve noise, break noise and so on. The limited justification with respect to cost/benefit by Ahn et al [1] would then discourage the industry's adoption of material damping improvement. In fact, recent studies have shown more benefits of damping improvement in concrete sleepers [4-10].

Despite the fact that train-track interactions induce dynamic loading conditions (either in service or abnormal condition), current design philosophy for railway concrete sleepers is based on the analysis of static and quasi-static stresses resulting from quasi-static wheel loads and essentially the static response of concrete sleepers. It is noted that a general manufacturing

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guidance for concrete sleepers was reviewed and recommended by *fib* [11]. However, the guidance was mainly focused on the manufacturing of concrete sleepers with little evidences related to the design and realistic behaviours of sleepers throughout their entire service life [12, 13]. European Standard EN 13230 [14] merely represents manufacturing and testing criteria for railway sleepers for quality control and benchmarking purpose (focusing only on test methods). All test methods (for static, cyclic and high-cycle fatigue) have been described based on a 3-point-load test system over on a simple roller-roller support condition. This shortfall has led to the lack of thorough understanding and insight into railway sleepers, which are safety-critical components of track systems. Most recent research is literally based on the standardised test methods and the test results cannot relate to in-service performance [15-20]. The potential consequence of such uncertainties can lead to detrimental train derailments, causing losses of lives, financial penalties, and operational downtime within an urban environment [21, 22].

In reality, cracking in railway sleepers can incur when the bottom fibre stress is larger than tensile strength of concrete. The premature cracking of concrete sleepers has been detected in railway tracks. The principal cause of cracking is the infrequent but high-magnitude wheel loads produced by a small percentage of "out-of-round" wheels or railhead surface defects, which are crudely accounted for in any design and test standards (including EN 13230) by a single load factor in design (or *k* factors for test criteria). These prescribed factors in either design or testing have very little to none of relationship with real behaviours of railway concrete sleepers, especially considering their entire service life. In fact, its scientific origin is somewhat questionable. In addition, it is important to note that high cycle fatigue failure of railway sleepers have never been observed in Japanese railway systems and such the absence is rather similar in other countries [23]. This has exposed the myth whether high-cycle fatigue would be of any concern when the concrete cross-sections in services are generally kept under compression due to prestress. Based on the current design methods (either by European EN 13230 or other international standards, e.g. Australia AS 1085.14 or American AREMA Manual Chapter 30), the cracked sleepers must be theoretically replaced by new ones, resulting in a costly maintenance budget each year. In reality, concrete sleepers are embedded in ballast or in mass concrete slabs. Crack detection is neither normally carried out by visual inspection nor any NDT&E approach. This has raised a paradox political game between manufacturers and asset managers about the shared responsibility and risk. Such the critical issue is hidden under other more pressing demands by other highly-publicised rail problems.

The paper under discussion [1] presents the importance of dynamic properties (e.g. stiffness, modulus, and damping) for concrete sleepers. The paper highlights the necessity to identify and improve dynamic properties and damping characteristics for railway concrete sleepers. However, the benefit of damping on a larger scale of track system was not addressed in that paper. As such, this letter is the first to demonstrate the insightful benefit of material damping at a track system level, which will better inform railway and track engineers who can implement such technology within the context of rail infrastructure systems. For concrete sleepers under operational traffics, a dynamic analysis (using dynamic properties of railway track, its components, and materials) has been recommended as an essential part of the design process [24, 25, 26]. This is because the dynamic resistance of the PC sleepers (i.e. serviceability, dynamic toughness and endurance, and impact strength) required by limit states design approach are influenced significantly by the damping and dynamic properties of materials and components. Without systems-thinking consideration of dynamic effects (load effects, resonances and resistance), the sleepers can lead to poor track serviceability and differential track settlements as shown in Fig. 1a. There is a misunderstanding that track decay rate (track system damping) is sufficient and there is no need to further improve individual component damping. However, the evidence in Fig. 1a signifies the importance of dynamic damping of materials and components in minimising localised damages. Track decay rate does not play a key role in structural vibration damaging track components. In real life, ballast breakages, ballast densification and pulverisation, sleeper cracks, fastening damages can be observed in ballasted tracks although the track decay rate of ballasted track might be significant. On this ground, the initiative to enhance damping characteristic of materials and components are very important and the dynamic properties should be the precursor in the design for improving durability, resilience and reliability of the track components [27, 28]. Clearly, Fig. 1b demonstrates the effectiveness of damping on the vibration suppression of railway concrete sleepers. It can be noted that the material damping can suppress broad frequency spectra of vibration. The insertion loss at the first bending mode can be ranging from 3 dB (2% damping) to 12 dB (10% damping), while, at the second bending mode, it can suppress from 4 dB (2% damping) to 15 dB (10% damping) of track vibration. The dynamic effects can be attenuated considerably, resulting in much lesser dynamic defections, bending stresses, and magnification factors.

Figure 1

The new design and manufacturing of railway sleepers should thus adopt such important aspects as the realistic track load spectra, the load characteristics of actual dynamic forces applied to the railway track, and the rational limit states design concept that is taking care of the realistic loading conditions and the true behaviour and dynamic capacity of the sleepers. The incorporation of dynamic resistance (derived from dynamic stiffness, modulus and damping of materials and component) is essential and central to the rational limit states design concept for concrete sleepers. The dynamic resistance can indicate the durability, resilience and reliability of railway concrete sleepers exposed to uncertain operational environments [29]. It has been reported also that by using dynamic design method, more sustainable railway sleepers can be achieved. It is thus very important that railway and track engineers implement the new innovation that can improve the sustainability and resilience of rail infrastructure systems [30]. Imagine that by saving 15% to 20% of material wastes in 1 million sleepers, rail industry can reduce over 1,200 ton of CO_2 emission together with significant amount of energies used and expenditures for excessive manufacturing, logistics, construction and maintenance.

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Figure 1 a) Real evidence of structural vibration impairing track performance and damaging track components. Obvious track gradient implies that any drainage problem could be minimal in this situation. (Credit: Kaewunruen, Photo Taken in 2017)

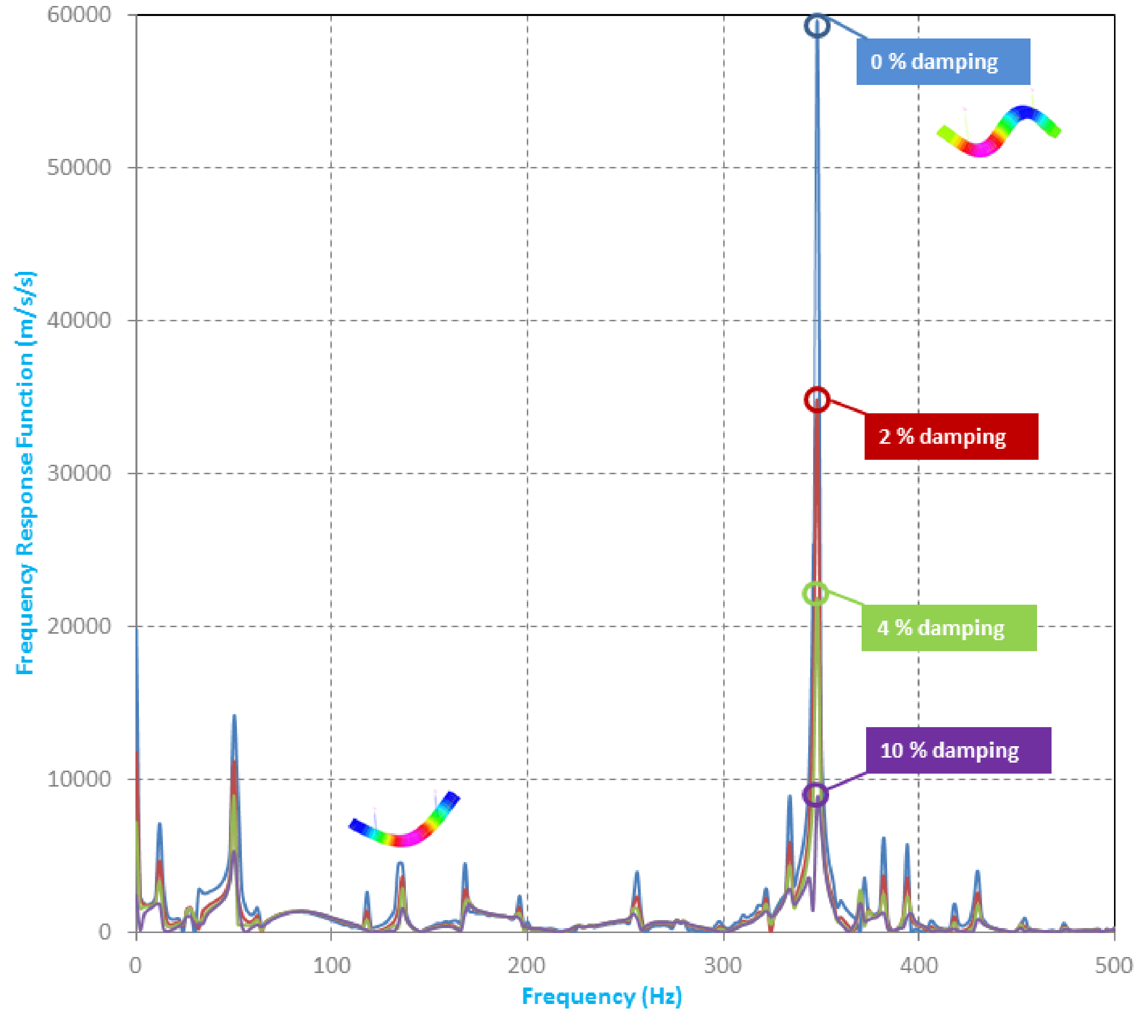

Figure 1 b) Frequency response functions of railway sleepers (the first bending resonance is at 143 Hz; and the second bending mode is at 370 Hz). These frequency response functions are obtained from frequency-based modal analyses of railway sleepers.