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Reply

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This paper responds to the discussion [1] by Dr. K. Giannakos over our technical note [2]. In fact, the authors welcome any comments to improve our research and practical experience related to railway sleepers. In the discussion comment letter [1], Dr Giannakos discussed whether or not static testing of railway prestressed concrete sleepers has any value in the engineering field. The discusser based his comments on the need for dynamic testing for the determination of the bearing capacity of concrete sleepers on the provisions from EN13230-2 and also inappropriately stated that 'it is misleading to use static not dynamic tests'.

Based on our extensive experience in both actual rail industry and academia (exemplified evidences in Refs: [2–121]), it is very well known that railway concrete sleepers (or railroad ties) are a structural and safety-critical component in track systems. Their main duties are to distribute the load as well as to secure rail gauge during train passages. Although there exist two design principles (permissible stress and limit states design concepts), their design takes into account both static and dynamic loading conditions together with their associated static and dynamic structural behaviours [122–124]. Despite the use of the prestressed concrete sleepers in railway networks over 55 years, their design and behaviour are neither thoroughly understood nor well documented. In particular, little information is available when the concrete sleepers are modified ad hoc and in situ. Without appropriate structural design and engineering analysis, the structural safety and engineering reliability of railway track systems can be impaired or mismanaged. A critical review of existing standard design codes (e.g., European Standard EN13230-2, American Standard AREMA C4, Australian Standard AS1095.14, or American Concrete Institute, ACI) reveals that there is a necessity to investigate such the important aspects [1]. On this ground, it is important to note that it is the first time that the effect of holes and web openings on the toughness and ductility of concrete sleepers is addressed in a systematic way [2]. Static testing is the first step in studying the behaviour of sleepers with holes and web openings, which was presented in [2] to inform the engineering community about the initial results, and dynamic testing is the next step forward (to be published in due course). The improved understanding will help railway and track engineers to determine structurally appropriate retrofitting approaches for prestressed concrete sleepers with the holes and web openings in practice.

Based on the international railway practices, there are two main design principles that have been commonly used to describe or predict the behaviour of railway sleepers (using any type of materials) [4,5]. The traditional design method that has been used for over many decades is based on the 'permissible stress design principle' while the new performance-based design method considers 'limit states design concept' [28,29]. The life span of concrete sleepers can also be varied. In Australasia, North America, Asia and South Africa, the sleeper design life is about 50 years since the uncertainties have been considered in design and maintenance (asset operations). In Europe, the sleepers must last more than 70 years. In addition, each country has adopted different material testing methods that resulted in different materials' strength and behaviour used in the design processes. With these factors in mind, a key performance criterion in the existing design principles (i.e., limit states design concept and permissible stress design principle) still rely on the ultimate capacity from the combined static stresses. In a structural design, ample ultimate strength and capacity of engineering structures and components must always be ascertained [124–127]. It is important to note that the ultimate capacity of the structural concrete members indicates many structural features with respect to dynamic and service performance of the components [128–131].

In reality, railway track structures are often subjected to the dynamic loading conditions due to wheel/rail interactions associated with the abnormalities in either a wheel or a rail [3]. The magnitude of the dynamic impact loads per railseat can vary from 200 kN and can sometimes be more than 600 kN, whilst the design static wheel load per railseat for a 40-tone axle load could be only as much as 110 kN [120,121]. All static, quasi-static, and impact loads are very important in the design and analysis of a railway track and its components. Generally, dynamic loading corresponds to the frequency range from 0 to 2000 Hz due to modern design of track vehicles. The shape of impact loading varies depending on various possible sources of such loading, e.g., wheel flats, out-of-round wheels, wheel corrugation, short and long wavelength rail corrugation, dipped welds and joints, pitting, and shelling. Wheel/rail irregularities induce high dynamic impact forces along the rails that may greatly exceed the static wheel load. In general, the dynamic load characteristics are considered in the design and analysis using 'impact factor' or 'dynamic amplification factor'. All of the design methods embrace the factor in the calculation of principal static stresses and their redistribution. This is the reason why ultimate static response has come to play a key role and why static behaviour is essential to enable structural failure mode prediction.

Figure 1 shows an actual statistical data of annual wheel loading obtained from railway networks in Australia. This track force measurement offers a clear insight that the dynamic load cases used in standard type tests (i.e., prescribed in EN13230-2) are not supposed to apply for understanding the sleeper behaviour. In fact, the prescribed dynamic load cases are adopted for performance benchmarking purpose. On this basis, the research presented in [2] is not misleading but, on the other hand, offers unparalleled insight into sleeper behaviours under the specific conditions (with holes and web openings). The insight into sleepers' toughness and ductility will ensure that any concrete sleeper can be structurally, safely retrofitted and modified for add-on fixture in practice.

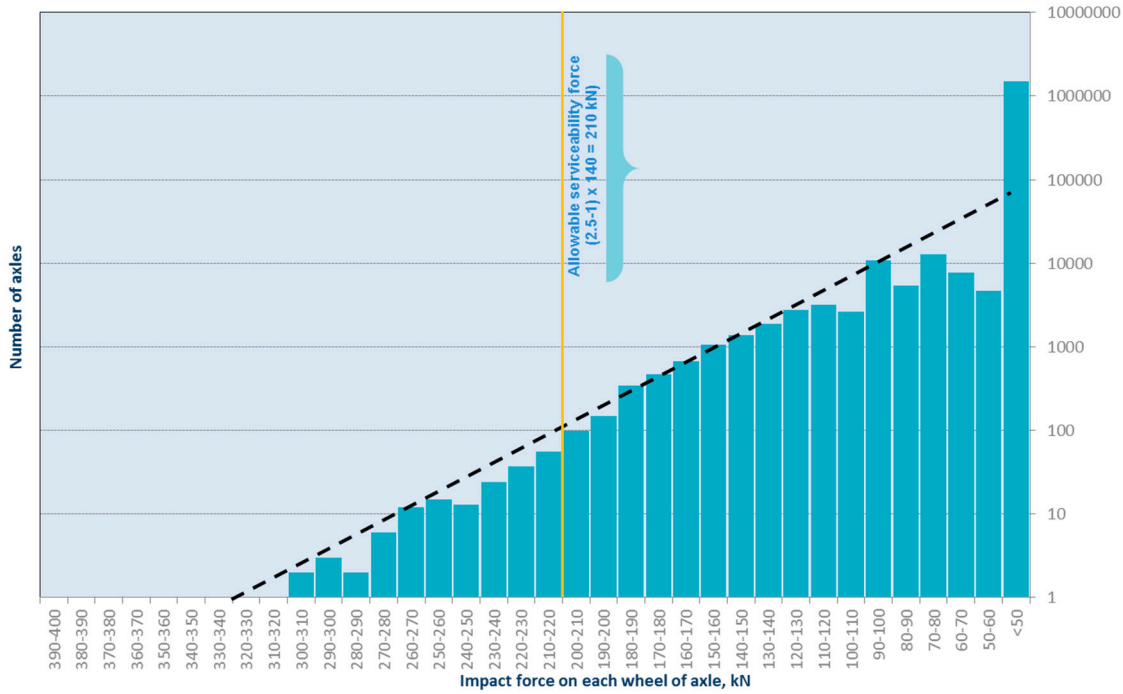

Figure 1. A real example of typical statistical data of annual wheel loading on tracks. These impact components are imposed on top of static 28-tonne axle load, which is the majority of load occurrence. Note that the allowable serviceability load can be derived from the allowable dynamic impact factor of 2.5 (prescribed). In general, the railseat load is about 70%–80% of the dynamic wheel load [125,132,133].

The permissible stress design concept has fundamentally dominated in current Australian and most international design standards for prestressed concrete sleepers where various limiting values or reduction factors are imposed on material strengths and load effects. Alternatively, the limit states design concept is a more logical entity for use as the design approach for prestressed concrete sleepers, in a similar manner to structural concrete members. It considers both strength and serviceability. A simple pseudo-static (using factored load) approach can be used in the design procedures of concrete sleepers under routine traffics. The new limit states design concept has been developed from comprehensive studies of the loading conditions, the static behaviour, the dynamic response, and the impact resistance of the prestressed concrete sleepers.

Figure 2 shows the flowchart for reliability-based structural design of railway concrete sleepers [89]. The errors and uncertainties involved in the estimation of the limit states design loads on the behaviour of a structure may be allowed for in strength design by using load factors to increase the nominal loads and using capacity factors to decrease the structural strength. The purpose of using any factor is to ensure that the probability of failure under the most adverse conditions of structural overload remains very small, which may be implicit or explicit in the rules written in a code. In structural design practices, toughness of a member is an important factor in the fail-safe design of structural systems, especially for the failure mode identification at ultimate state. The toughness characteristic has correlation with dynamic strength and endurance of structural members. In the technical note [1], the emphasis was placed on experimental investigations into structural toughness, which is an important characteristic to predict failure under ultimate and damageability limit states [39,85,135]. As such, there is no shortage of value since the research in [2] paves the essential fundamental for further research into sleepers' retrofit and modification. In addition, numerical study can use static test data for validation and enable virtual tests of the sleepers with holes and web openings under different limit states (i.e., dynamic and impact conditions due to accidental loading, fatigue life or endurance characteristics, etc.).

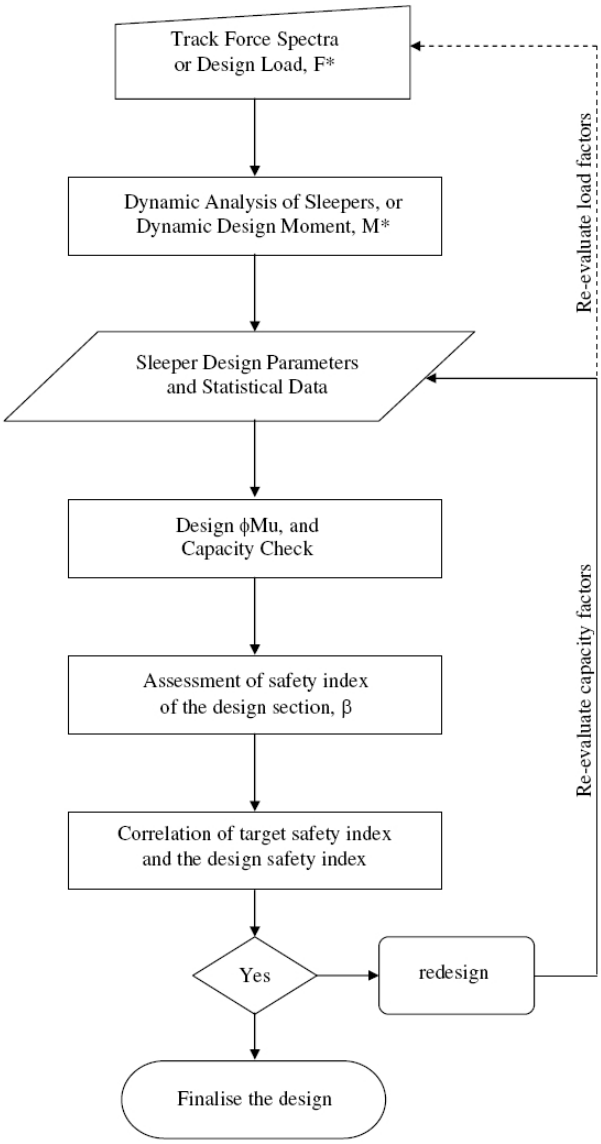

Figure 2. Flowchart for limit states design of railway concrete sleepers. The concept has been adopted in Europe and Australia [39,85,134]. Capacity design check stage requires in-depth understanding of structural failure, toughness and ductility of sleepers.

For dynamically compliant structures such as railway tracks, the fatigue life or endurance characteristic would likely be another factor in the serviceability limit state [39,85] because low and high cycle fatigue failure of railway sleepers may occur. Fatigue performance or 'endurance' of sleepers can be correlated to energy toughness [125,129]. In most cases, a ratio of dynamic over static performance is often used in asset modelling and management. Static tests are normally served as a datum or reference. Without static testing, the dynamic accumulative results are meaningless [20,21,136]. Additionally, it is noted from [136] that "*According to the standard (EN13230), the dynamic testing is regarded as non-obligatory optional testing that is conducted at the request of the end-user. The results obtained confirmed the reasons why standards do not require dynamic testing: dynamic (impact) safety coefficients obtained in the testing, compared to maximum allowable values, are greater than the relationship between the static safety coefficients and maximum allowable static safety coefficients. It is clear that the effect involving increase of bearing capacity of prestressed concrete sleepers occurs at dynamic cyclic load*." [136]. This finding is similar to a trend found in the past [129]. However, based on our previous relevant research [2–121], this fatigue serviceability limit state is critical for aging sleepers and should be considered for load rating [34,35].

In summary, the standard type testing has been developed and adopted for performance benchmarking. The technical note (under the discussion) neither misleads nor provides negligible value. In contrast, the work provides a fundamental step towards better correlation between endurance and toughness of sleepers with holes and web openings. It also improves the insight into structural failure that helps railway track engineers determine appropriate ad hoc and in situ modification methods for the structural and safety-critical components in railway track systems. The goal is to improve public safety and reduce unplanned track maintenance (contributing towards extra costs, time, energy and carbon footprint) due to premature failure of railway sleepers [137,138]. On this ground, by inappropriately publishing his comment, the discusser harassed the authors by unfairly accusing them of providing misleading research information.

Conflicts of Interest: No conflict of interest.

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