April 2008

Probabilistic Impact Fractures of Railway Prestressed Concrete Sleepers

Sakdirat Kaewunruen
Austrak Pty Ltd, sakdirat@hotmail.com

Alexander Remennikov
University of Wollongong, alexrem@uow.edu.au

Advanced Materials Research Vols. 41-42 (2008) pp 259-264
online at http://www.scientific.net

Probabilistic Impact Fractures of Railway Prestressed Concrete Sleepers

Sakdirat Kaewunruen[1,2, a] and Alex M Remennikov[2,b]

[1]Austrak Pty Ltd, Brisbane QLD 4105 Australia

[2] University of Wollongong, Wollongong NSW 2522 Australia

[a]skaewunruen@austrak.com, [b]alexrem@uow.edu.au

Keywords: Probabilistic impact, crack, railway prestressed concrete sleeper, fracture, drop-weight impact testing.

Abstract. Cracks in railway prestressed concrete sleepers are often caused by the infrequent but high magnitude impact forces. These impact forces are attributed to the wheel or rail abnormalities, e.g. wheel flat, corrugation, dipped joint, etc. The emphasis of this paper is placed on the corresponding fractures of railway prestressed concrete sleepers in track systems under the probabilistic impact loadings. The statistical data of impact loadings in Central Queensland have been obtained through the collaborative project under the research framework of the Australian Cooperative Research Centre for Railway Engineering and Technologies. It is found that for the heavy haul railway network, the track structures, especially the concrete sleepers, may experience the impact loading from 400kN up to 800kN. The corresponding probabilities of such load occurrences are ranging from one in twenty years to one in thousands of years. It is very important for the design and maintenance perspectives to investigate the impact behaviour of concrete sleepers under the impact loadings. This paper presents the impact fractures of railway prestressed concrete sleepers under the single impact loading associated with the probability of occurrence in the soft track environment. Visual interfacial cracks have been evaluated for the crack length and width along the sleepers in relation to the probability of load occurrence.

Introduction

Ballasted railway track is a common means for transportation and freight. It consists of two major parts, which are superstructure and substructure. The superstructure includes steel rails, the fastening systems and sleepers; whilst the ballast, sub-ballast, sub-grade and formation, constitute the sub-structure. Figure 1 illustrates the schematic ballasted track. It should be noted that ballasted track has many superior advantages; for example, the construction costs are comparatively low, the maintenance and repair of track and its components are convenient, it has high damping and very good drainage properties, and noise can be controlled [1]. In general, railway track is subjected to a variety of dynamic loading conditions. Accordingly, understanding into the dynamic behaviour of railway track and its components is essential in order to evaluate the structural safety and service life of the railway track components. In practice, railway officers perform inspections on tracks using a diagnostic car and visual observation. Indicators of component failure rely partly on visible defects of rails, fasteners, rail pads, and sleepers. According to AS1085.14 [2], the concrete sleepers should be replaced if major crack in the sleeper occurs. As noted in the review [3], the principal cause of cracking is the infrequent but high-magnitude wheel loads produced by a small percentage of "bad" wheels or railhead surface defects. For instance, the typical loading duration produced by a 2mm wheel flat is about 1-10 msec, while the force magnitude can be over 400 kN per rail seat. Those loads are of short duration but of very high magnitude. However, the guideline and criteria for sleeper maintenance are not clear and there is a widespread notion that the concrete sleepers possess large amount of reserve strength [4].

A recent study showed that there is a potential possibility for railway sleepers subject to severe impact loads [5]. In general, the dynamic load characteristics considered in design and analysis include the magnitudes of impact loading and the variety of pulse durations. The loading and strain rate effects tend to complement the strength of materials whilst the high loading magnitude devastates the structural members. In structural design and analysis, the public safety must not be compromised so the design loads must be appropriate and associated with the long return periods which would optimally provide the low probability of occurrence on structures during their design life. For further explanation, a design load that is associated with 50 year return period has the likelihood of occurrence that the design load might happen only once in 50 years regardless of the structural life span.

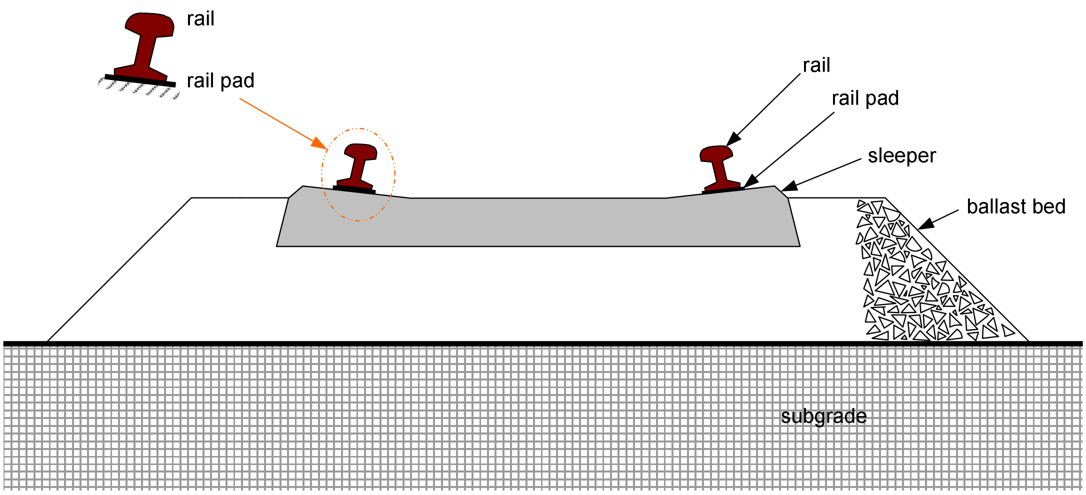

Fig. 1 Typical ballasted track structure

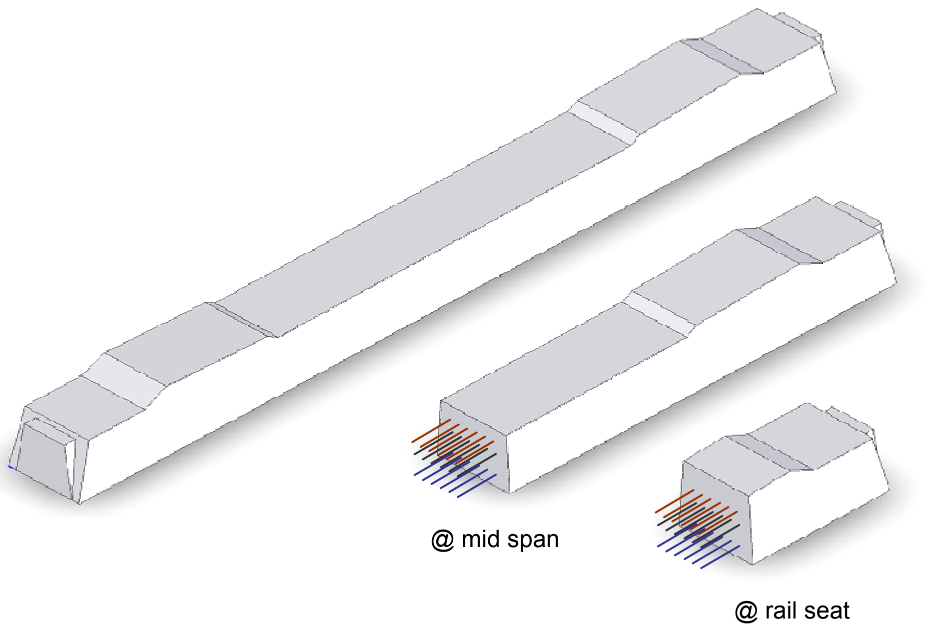

Fig. 2 General profile and cross-sections of prestressed concrete sleepers

For design and analysis of prestressed concrete sleepers (see in Figure 2), certain design loads associated with probabilistic return periods (related to the importance level of the structure) must be considered. The dynamic crack propagations of prestressed concrete sleepers in railway track structures under probabilistic impact loads associated with the design probability of occurrence (and return period) have not yet been adequately addressed, although they are the key for the development of performance-based design of concrete sleeper (Murray and Cai, 1998). This paper presents experimental results of prestressed concrete sleepers in soft support condition or in a '*soft track*'. Full-scale prestressed concrete sleepers were provided by the Australian manufacturer, Austrak. Impact testing was carried out using the new high-capacity impact testing facility at the University of Wollongong. The results will lead to the development of impact damage classification as a performance indicator of prestressed concrete sleepers.

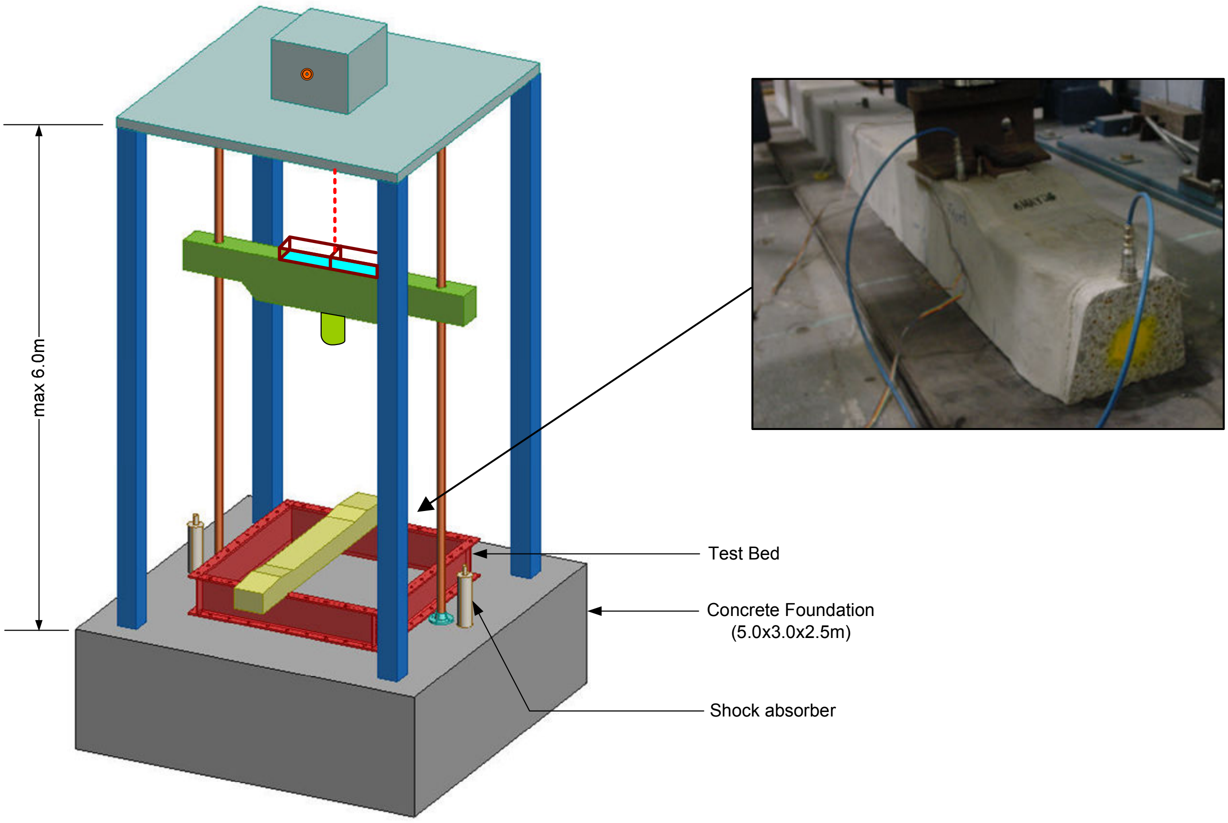

Fig. 3 Schematic layout of the drop-weight impact test rig

Experimental Overview

The prestressed concrete sleepers were supplied by an Australian manufacturer, under a collaborative research project of the Australian Cooperative Research Centre for Railway Engineering and Technologies (Rail CRC). The typical full-scale prestressed concrete sleepers as shown in Figure 2, which are often used in broad gauge tracks, were selected for these tests. The dimensions and shape of the prestressed concrete sleepers used in the impact tests can be found in the companion paper [6]. The average compressive strength of cored concrete is 88.5MPa in accordance with AS1012.14 [7]. An alternative approach that uses polymeric materials (or '*rubber mat*') to replace the real ballast has been adopted for a specific use in Australian Standard, AS1085.19J [8].

In this study, the drop height and drop mass were selected to simulate a typical impact load due to a wheel flat of 20-25mm, which could generate an impact of over 600kN. The weight of the projectile was set as 5.81 kN (592kg), and therefore, the drop height becomes the only variable. The schematic of the impact testing machine is illustrated in Figure 3. The core of the test rig is the free-fall hammer that can be dropped from a maximum height of 6m, or equivalent to the drop velocity up to 10 m/s. The impact load was monitored and recorded by the dynamic load cell connected to the computer. Efficiency of drop weight hammer has been obtained through the calibration tests done using high speed camera. It is found that due to friction of guiding runner the hammer's experimental velocity reduces to 98% of theoretical velocity.

At each drop height, a new sleeper was used. The measurements in an impact testing include the impact load history, the accelerations, the crack width, and the damage severity. The device for measuring the impact load history is the dynamic load cell. The accelerations were captured by using the Dytran accelerometers. Crack length and width was obtained by using the magnifier glass telescope with a resolution of 0.1mm. The length of the residual cracks is the main indicator for the durability and serviceability of the prestressed concrete sleeper in practice [9] whereas the residual crack sizes are fairly close to the maximum opened crack. The data acquisition system was triggered by the impact loading signal from the freely drop-weight hammer itself during a test. Subsequently, the impact load history, the accelerations, and the strain signals can be captured. Table 1 shows the test program of this study.

Table 1 Test program

Support condition	**Impact force (kN)**	**Related return period (years)**	**Impact Energy (J)**	**Number of blows**
Soft track	500	50	1,421	1
	740	2000	2,250	1
	1,500	>1,000,000	8,130	1

Results and Discussion

The first cracks that formed in the sleeper under the impact load of 500 kN were '*hair line*' flexural cracks at the bottom fibre of loaded railseat. It is important to note that there is no crack occurred at the other railseat. Figure 4 shows the crack pattern of the prestressed concrete sleeper under the single impact of 500 kN. It is found that there is no major crack occurred. The average crack length measured from both front and rear faces is about 97.5mm, while the crack width is around 0.01-0.02mm.

The first cracks that formed in the sleeper under the impact load of 740 kN were also flexural cracks arising from the bottom fibre of loaded railseat, whilst no crack can be observed at the other end. Figure 5 shows the crack pattern of the prestressed concrete sleeper under the single impact of 740 kN. It is found that the lengths of cracks are quite significant, which are more than half of the sleeper's cross section. The average crack length measured from both front and rear faces is about 137.5mm, while the residual crack width is around 0.01-0.03mm.

The first set of cracks in the sleeper under the impact load of 1,500 kN were a combination of flexural cracks arising from the bottom fibre and spalling of concrete in the top fibre (under compression) of loaded railseat. On the other hand, there is no crack observable at the other railseat or at the mid span. Figure 7 shows the crack pattern of the prestressed concrete sleeper under the single impact of 1,500 kN. It is found that the lengths of cracks are substantial, as three cracks can be visibly noticed. The longest (centre) crack length measured from both front and rear faces is about 168.5mm, while the residual crack widths are varied from 0.04mm to 0.08mm.

Fig. 4 Cracks in a sleeper in soft track after a single impact of 500 kN (a) front; (b) rear

Fig. 5 Cracks in a sleeper in soft track after a single impact of 740 kN (a) front; (b) rear

Fig. 6 Cracks in a sleeper in soft track after a single impact of 810 kN (a) front; (b) rear

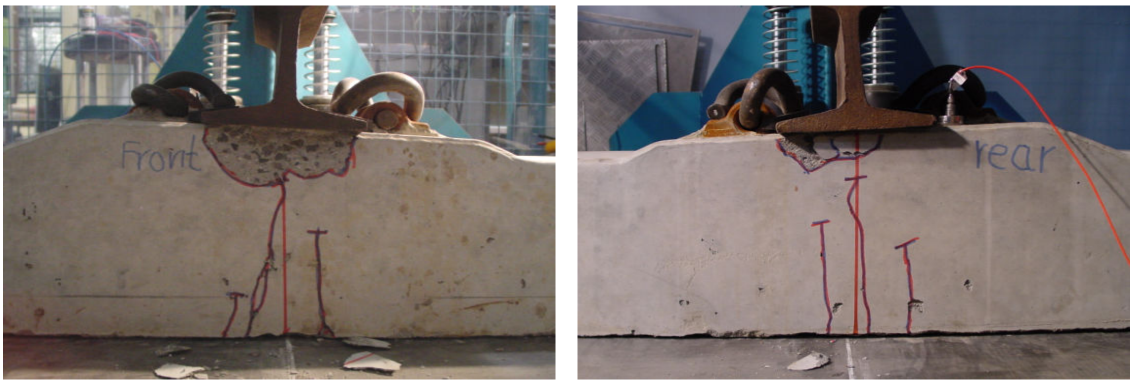

Fig. 7 Cracks in a sleeper in hard track after a single impact of 1,500 kN (a) front; (b) rear

Summary

Figure 8 concludes the relation between the impact loads and impact energy input versus the normalised crack length of the prestressed concrete sleeper under the impact testing conditions. The correlation indices provide the sufficient confidence in order to predict the dynamic crack propagation of the prestressed concrete sleeper in soft track environment.

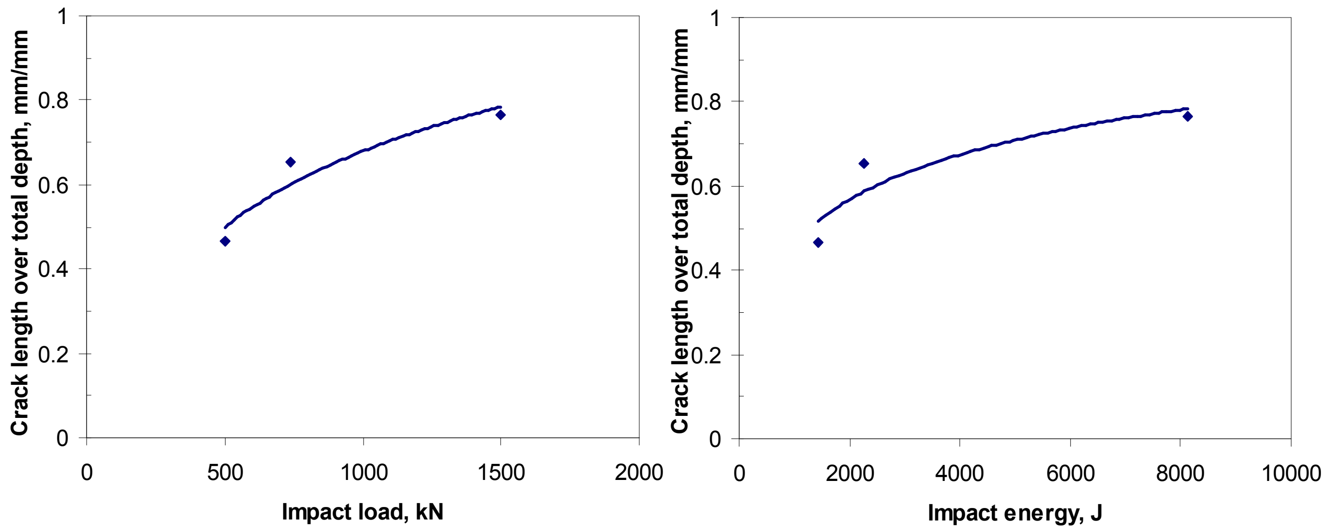

Fig. 8 Crack propagations in the sleepers under single impact loads: left) impact load; right) impact energy

Acknowledgement

The authors are grateful to the Australian CRC for Railway Engineering and Technologies (Rail-CRC) for the financial support via the Project No 5/23. The authors would like to thank Alan Grant, Ian Bridge, Bob Roland, and Jason Knust, for their assistance during the course of this project.

References

[1] Esveld C, *Modern Railway Track*, The Netherlands MRT Press, (2001).

[2] Standards Australia, “Railway track material - Part 14: Prestressed concrete sleepers” *Australian Standard: AS1085.14-2003*, (2003).

[3] Murray M and Cai Z, Literature review on the design of railway prestressed concrete sleeper. *RSTA Research Report*, Australia, (1998).

[4] Kaewunruen, S. and Remennikov, A.M. Experimental and numerical studies of prestressed concrete sleepers under static and impact loads, invited in *Civil Computing*, 25-28 (2007).

[5] Leong, J. Development of limit states design of railway track, *MEng Thesis*, Queensland University of Technology, Queensland, Australia (2007)

[6] Kaewunruen, S. and Remennikov, A.M. Dynamic effects on vibration signatures of cracks in prestressed concrete slepeers, *Proceedings of International Conference on Structural Intrigety and Failure*, Perth, Australia (2007)

[7] Standards Australia, Method of testing concrete – Method for securing and testing cores from hardened concrete for compressive strength, *Australian Standard: AS1012.14-1991*, (1991).

[8] Standards Australia, “Railway track material - Part 19: Fastening materials” *Australian Standard: AS1085.19-2001*, (2001).

[9] Wang, N. Impact resistance of concrete sleepers, *PhD Thesis*, Department of Civil Engineering, University of British Columbiam Cananda (1996).