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Sakdirat Kaewunruen
Austrak Pty Ltd, sakdirat@hotmail.com

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

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S. Kaewunruen[1], A.M. Remennikov[2]

[1] Austrak Pty Ltd. Brisbane, QLD, Australia (Formerly PhD Candidate at the University of Wollongong, Wollongong, NSW, Australia)
[2] University of Wollongong, Wollongong, NSW, Australia

Abstract
Interactions between the wheel of rolling stocks and the rail often generate interfacial impact forces to railway tracks. The dynamic impact loads are of very high magnitude but short duration, and are caused by either wheel or rail abnormalities such as flat wheels, dipped rails, etc. Although the possibility of the large impact loading to cause an extreme failure to an in-situ concrete sleeper could be very low about once or twice in the design life cycle, the damage of track components especially for the concrete sleepers is often observed. The railway sleeper is a major component of railway tracks. Its role is to distribute the load from the rails to the underlying ballast bed. Up to current knowledge, the behaviour of the in-situ prestressed concrete sleepers under the impact loading has not yet been thoroughly comprehended. In order to evaluate the resistance of railway concrete sleepers to impact loads, a high-capacity drop-weight impact testing machine was thus constructed at the University of Wollongong. It is currently the largest one of its kind in Australia with the maximum drop height of 6m. This paper demonstrates the experimental investigations, in order to evaluate the attenuation effect of rail pads on the impact behaviour of railway concrete sleepers. The impact tests were carried out using the prestressed concrete sleepers manufactured in Australia. This study enables and enhances the methodology to analyse and design for the prestressed concrete sleepers at ultimate limit states.

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1. Introduction

Building structures for transportation are an important drive for the social and economic growth of any country around the world. It is commonly understood that railway system provides the best and safest transportation means for either passenger or freight nowadays. Among the modern types of railway tracks, sleepers or ties are often used in both ballasted and ballastless railway tracks for rural, suburban, or inner city rail networks. The financial viability of the ballasted track relies on its cost-effectiveness in construction, maintenance, and renewal. Esveld (2001) claimed that ballasted railway 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 characteristics and very good drainage properties, and noise and ground-borne vibrations can be controlled. At present, the understanding and knowledge of behaviour of railway tracks in realistic conditions are insufficient. Current knowledge has led to the over-conservative, empirical method in analysis and design of concrete sleepers. It also results in the unrealistic representation in the context of test methods. In general, the railway tracks are subjected to a variety of dynamic loads, understanding the dynamic track behaviour is essential in order to evaluate the structural safety and service life of the railway track components.

There are two main parts of ballasted railway track, including the super-structure and the sub-structure. The super-structure consists of steel rails, fastening systems, and railway sleepers (or so-called 'railroad ties' in the US); The sub-structure is formed by ballast, sub-ballast, sub-grade and formation. Figure 1 illustrates the ballasted track components. Although railway prestressed concrete sleepers have been developed and utilized in railway industry for over 50 years, current design approach has been based on permissible stress design whereas the structural behaviours or deformations are kept within the elastic range. The design load calculation for structural design is taken from static or quasi-static loads, by taking into account a dynamic impact factor multiplying with the wheel load. The railseat load calculation is obtained from the simple load distribution. The design bending moments are considered from static load cases and the simplification of elastic-foundation-supported beam theory. It should be noted that the design life span of the concrete sleepers is also considered to be around 50 years (Standards Australia, 2003).

Recently, major research attention has been placed on vertical static and dynamic forces as they are the main source of railway track problems when trains are operated at different speeds and different static axle loads. It has been found that wheel/rail interactions result in much higher-frequency and much higher-magnitude forces than simple quasi-static loads. These forces are often called as '*dynamic wheel/rail*' or '*impact*' forces. The typical impact loadings due to train and track vertical interaction has been presented in Remennikov and Kaewunruen (2007a) with particular reference to the shapes of the typical waveforms of impact loads generally found in railway track structures. Figure 2 depicts the typical impact loads due to a wheel flat (Wu and Thompson, 2001).

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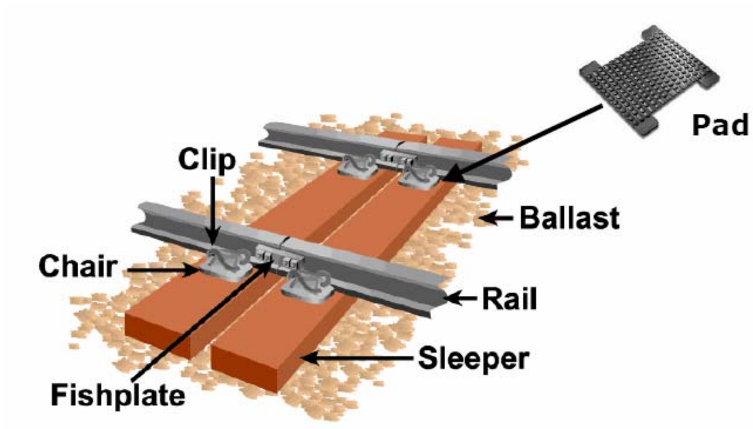
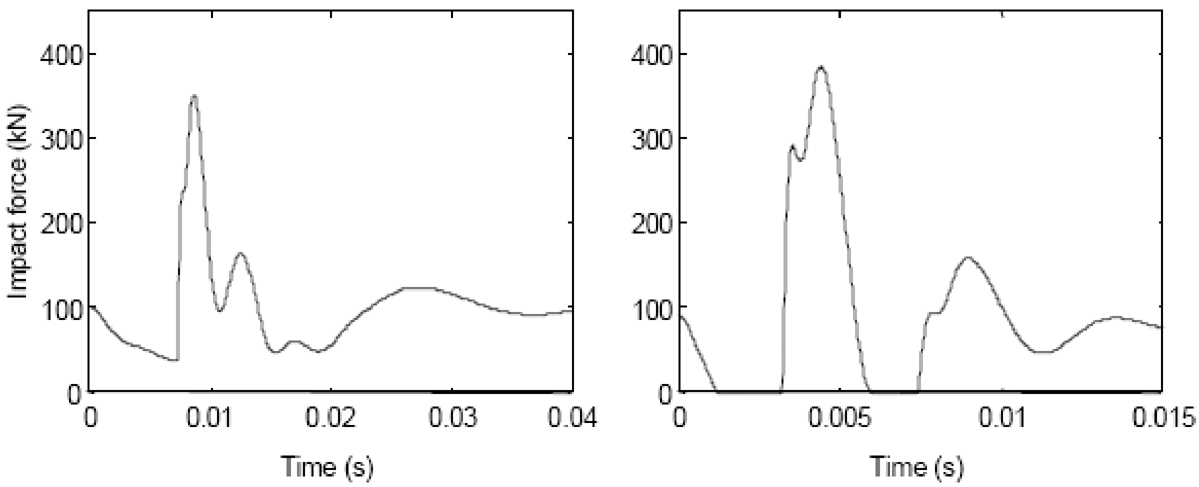


Figure 1 Typical rail track (Kaewunruen and Remennikov, 2008)



a) at train speed 30 km/hr *b) at train speed 80 km/hr*

Figure 2 Dynamic forces due to 2 mm rounded wheel flat (Wu and Thompson, 2001)

Interactions between the wheel of rolling stocks and the rail often generate interfacial impact forces to railway tracks. The dynamic impact loads are of very high magnitude but short duration, and are caused by either wheel or rail abnormalities such as flat wheels, dipped rails, etc. Although the possibility of the large impact loading to cause an extreme failure to an in-situ concrete sleeper could be very low about once or twice in the design life cycle, the cracking damage of track components especially for the concrete sleepers is often observed (Murray and Cai, 1998; Leong, 2007). The railway sleeper is a major component of railway tracks. Its role is to distribute the load from the rails to the underlying ballast bed. However, the force content is filtered and attenuated by the softtening medium, rail pad installed between sleeper and rail (Kaewunruen and Remennikov, 2007a). Up to current knowledge, the behaviour of the in-situ prestressed concrete sleepers under the impact loading has not yet been thoroughly comprehended. It is expected that rail pads attenuate the impact force on rail seat but their effectiveness is unclear. Grassie (1987; 1989) investigated the dynamic load attenuation by rail pads in laboratory and on track. However, the dynamic load type and magnitude were limited to an extent (<100 kN). So far, the attentuation performance of rail pads under severe impact loads has not been addressed.

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Figure 3 High-capacity drop-weight impact machine at the University of Wollongong

In order to evaluate the resistance of railway concrete sleepers to impact loads, a high-capacity drop-weight impact testing machine was thus constructed at the University of Wollongong. It is currently the largest one of its kind in Australia with the maximum drop height of 6m, as illustrated in Figure 3. This paper demonstrates the experimental investigations, in order to evaluate the attenuation effect of a high-density polyethylene (HDPE) rail pad on the impact behaviour of railway concrete sleepers. The impact tests were carried out using the prestressed concrete sleepers manufactured in Australia. This study enables and enhances the methodology to analyse and design for the prestressed concrete sleepers at ultimate limit states.

2. Experimental Overview

2.1 Specimens

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, which are often used in broad gauge tracks, were selected for these tests. The dimensions and shape of the prestressed concrete sleeper are shown in Table 1. The high strength concrete material was used to cast the prestressed concrete sleepers, with design compressive strength at 28 days of 55 MPa, and the prestressing steels used were the high strength with rupture strength of 1860 MPa. However, the cored samples, drilled from the sleepers, were taken for a confirmation test, as per the Australian Standard AS1012.14 (1991). It was found that the average compressive strength at the test age of about two years was 80 MPa. It is believed that the high strength prestressing wires are of high quality and the strength will not change during time. The rail pad used in this study is high-density polyethylene (HDPE) rail pad with the thickness of 7.5mm. The dynamic and mechanical properties of the rail pad can be found in Remennikov and Kaewunruen (2005). A criterion for this pad selection is because of the very high stiffness but moderate damping property of the HDPE pad, providing a conservative attenuation performance (lower bound) of the rail pad for track design purpose.

***Table 1**. Dimensions and masses of the test sleepers*

Mass	Gauge length	Total length	At railseat (m)		At centre (m)	
(kg)	(m)	(m)	width	depth	width	depth
206.0	1.60	2.50	0.20	0.23	0.21	0.18

2.2 Impact Testing

Severe impacts simulating actual probabilistic loads can be rendered using a free falling mass. The high-capacity drop-weight impact testing machine, which is currently the largest in Australia, has been developed as depicted in Figure 3. The thick rubber mat was used to replicate the ballast support. It was found that the test setup represents the concrete sleepers in general soft track systems (Standards Australia, 2001; Kaewunruen and Remennikov, 2007a; 2007b; 2007c). To apply impact loads, the drop hammer used has the weight of 5.81kN. At the railseat was installed the rail with fastening system to transfer the load to the specimens. 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, which is found about 98%. Experimental setup and impact tests were arranged in accordance with the Australian Standards as shown in Figure 4. The drop heights were increased step by step until sleeper cracks can be observed. Table 2 shows the experimental programs to investigate the attenuation effects of HDPE rail pad on the impact behaviour of the concrete sleepers. The drop heights were varied between 0.1m and 0.8m. The rail pad used in the test setup is the HDPE type.

***Table 2** Experimental programs*

Drop height (m)	**Use of rail pad** [Y: yes; N: no]	**Support condition**	**Use of softening media in contact zone**
0.1-0.8	Y and N	Soft	direct contact 1mm neoprene 2mm neoprene 3mm neoprene

Figure 4 Experimental setup

3. Results and Discussion

The impact forces measured from the dynamic load cell from direct contact between rail and impactor are presented in Figure 5. A hairline bending crack was firstly detected at the drop height of about 600mm for the concrete sleeper without rail pad, but the small shear cracks were also found after few blows at the drop height of 800mm. However, no major crack or any failure can be observed. From the test undertaken it is evident that the sleeper exhibits a significant amount of reserved strength. Figure 5 shows that the higher drop heights provide the larger magnitude of impact loading, but slightly reduce the shock duration. The magnitude of the shock loading associated with the flexure of the sleeper varies from 380 to 1,150 kN while the duration remains in a small range between 4 and 6 ms. It should be noted that the first peaks are related to the contact stresses at the contact zone between the impactor and the railhead. The actual flexural responses of the sleeper are most likely due to the second peaks. The first sharp spikes are ascribed by the inertial effect of the track structures and they can be filtered out by low-frequency pass bandwidth feature in LabView. The softening media were also installed between the railhead and impactor. The use of softening media reduces the impact force content. They extend the pulse duration whilst decrease the impact magnitude, depending on the thickness of the media. Further details can be found in Remennikov and Kaewunruen (2007b).

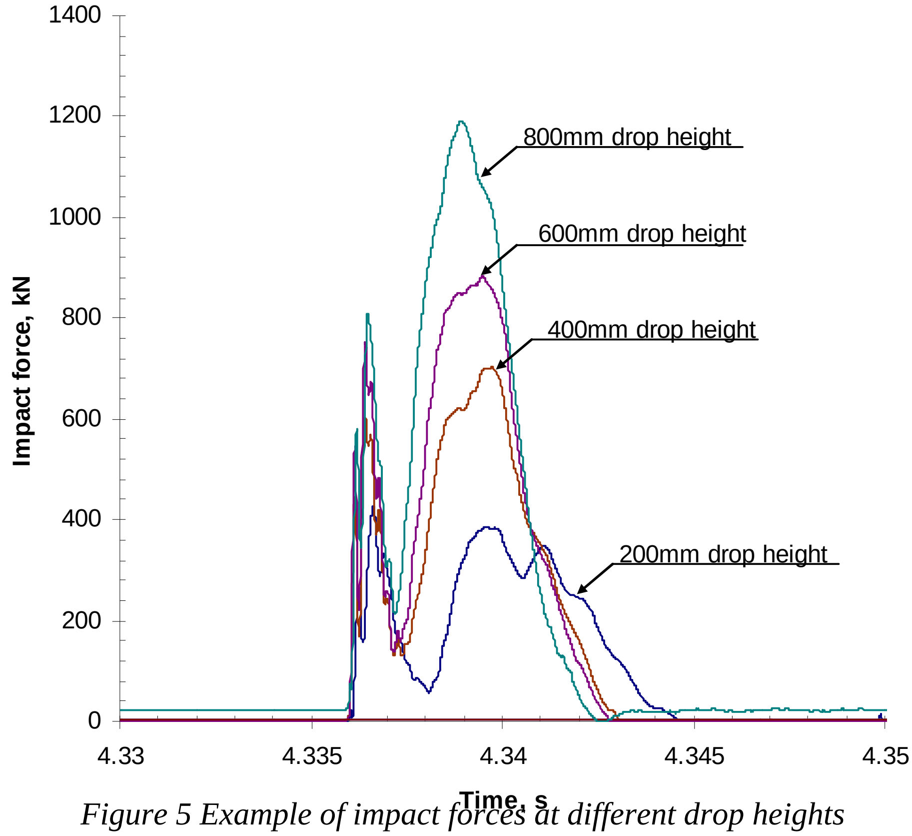

Figure 5 Example of impact forces at different drop heights

The strain gauges were installed at top and bottom fibres of the test sleepers to evaluate the resultant bending moment, as illustrated in Figure 6. The experimental results yield the scatter data as shown in Figure 7. It is found that the linear trends can be drawn as the good representatives of the scatter data. Although there is a large discrepancy in the data of the sleeper without rails pad, it should be noted that the dispersed data are belong to those tests performed after hairline crack occurred.

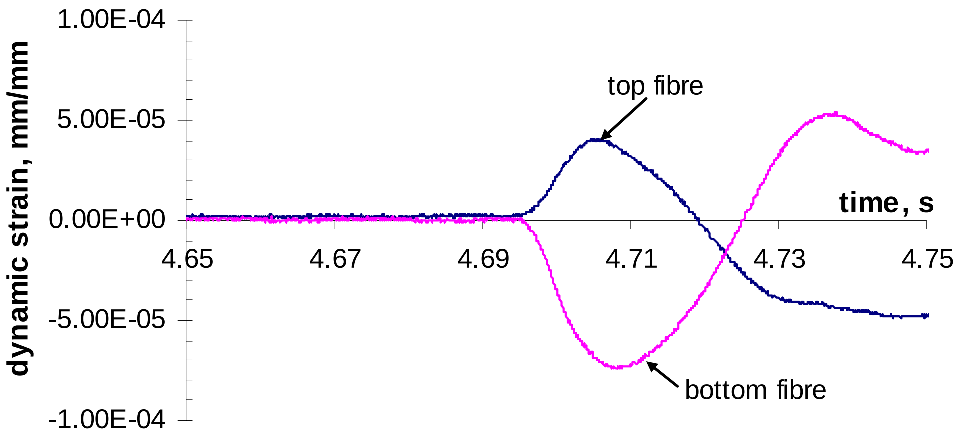

Figure 6 Example of dynamic strains at sleeper railseat due to a small drop (without rail pad)

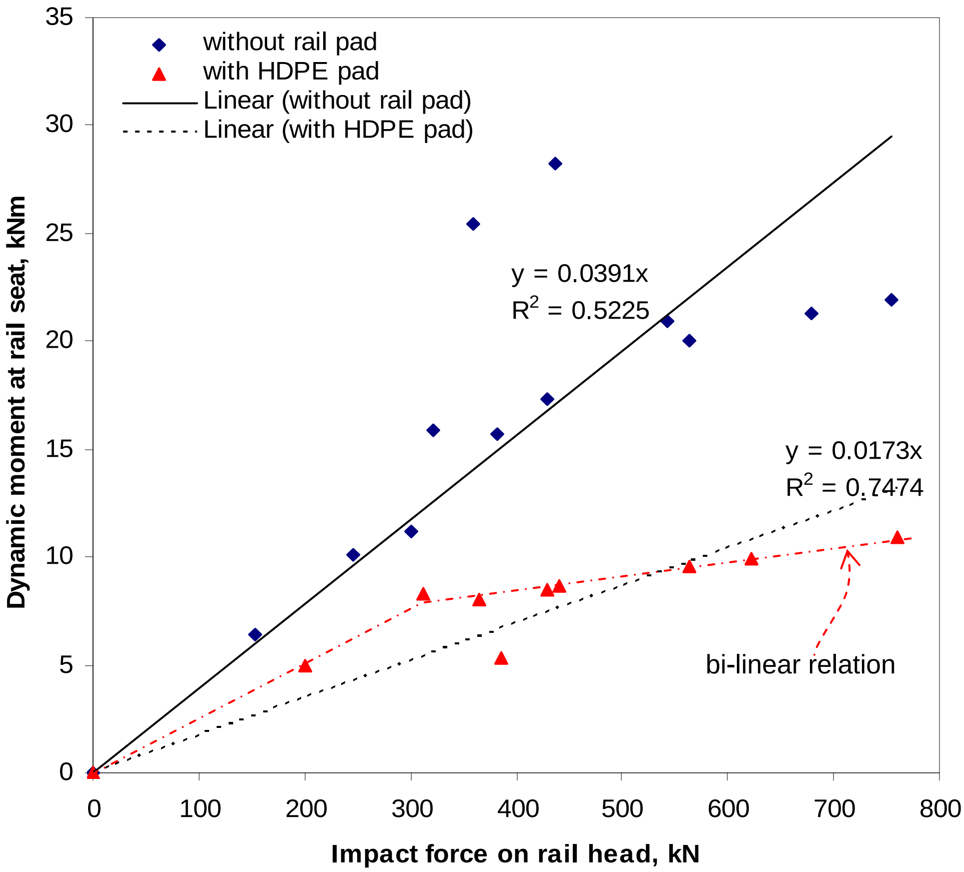

Figure 7 Dynamic bending moment at sleeper railseat

The estimated function between railseat moment (M) and impact force at railhead (I) for the concrete sleeper in soft track is about M = 0.039I when omitting rail pad and about M = 0.017I for the sleeper with HDPE rail pad. When the concrete sleepers crack, the large variation of results can be noticed. However, the experimental results illustrated in Figure 6 show that in the real track condition the rail pads can attenuate the impact responses of the prestressed concrete sleepers under severe impact loads up to 50 percent. It can be observed that the impact attenuation effect can be well represented by a bi-linear relationship whereas the attenuation performance is increasing as the loading condition increases. Under low impacts, the attenuation effect is relatively low or about 30 percent. In contrast, the rail pad tends to attenuate well above 50 percent under severe impact loading. Nonetheless, it should be noted that the attenuation effects are specific for different types of rail pads (Kaewunruen and Remennikov, 2007d). In this study, this HDPE pad is considered as to provide a lower bound of the attenuation performance of rail pads in existing railway tracks.

4. Concluding Remark

Wheel or rail defects have been found to cause the large impact load during the dynamic interaction between the wheel and rail. The impact load characteristics are typically of high magnitude but short duration. In general, the force magnitude varies between 300 and 400 kN, with the pulse duration from 1 to 10 ms. This magnitude of impact corresponds roughly the fifty-year return period, which is about only once in the design life span of concrete sleepers. Current knowledge has not appropriately addressed the attenuation performance of rail pads under high-intensity impact loads. This study conducted at the University of Wollongong, Australia, aims to understand more clearly the manner in which track components respond to the severe forces, and to clarify the performance of rail pads whereby the concrete sleepers in particular carry those effects. It is therefore very important to ascertain the spectrum and amplitudes of forces applied to tracks, as well as to develop a methodology to evaluate the rail pad effectiveness for wheel/rail impact attenuation to concrete sleepers.

This paper presents the investigation into the performance of HDPE rail pad, in order to attenuate the severe impact load on the rail interface. The techniques of free falling mass and contact stress alleviation have been demonstrated through the extensive experimental programs. The relationships between wheel/rail interface impact force and flexural moment acting at railseat of railway concrete sleepers have been investigated experimentally. With particular reference to the realistic track environment, the rail pad plays a significant role on the impact behaviour of the prestressed concrete sleepers. The uses of rail pad clearly demonstrate the preclusion of excessive dynamic stress from the rail to the railway sleepers and can reduce up to 50% of dynamic bending moments at rail seat of the prestressed concrete sleepers.

5. Acknowledgement

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