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Structural Behaviours of Railway Prestressed Concrete Sleepers (Crossties) With Hole and Web Openings

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Abstract

As the crosstie beam in railway track systems, the prestressed concrete sleepers (or railroad ties) are principally designed in order to carry wheel loads from the rails to the ground. Their design takes into account static and dynamic loading conditions. It is evident that prestressed concrete has played a significant role as to maintain the high endurance of the sleepers under low to moderate repeated impact loads. In spite of the most common use of the prestressed concrete sleepers in railway tracks, there have always been considerable demands from rail and track engineers to improve serviceability and functionality of concrete sleepers. For example, signalling, fibre optic, equipment cables are often damaged either by acute ballast corners or by tamping machine operation. There has been a significant need to re-design concrete sleeper to cater cables internally so that they would not experience detrimental or harsh environments. Accordingly, this study is the world first to experimentally investigate the effects of holes and web openings on structural behaviours of concrete sleepers under rail loading condition. The modified compression field theory for ultimate strength behaviours of concrete sleepers will be highlighted in this study. The outcome of this study will enable the new design and calculation methods for prestressed concrete sleepers with holes and web opening that practically benefits civil, track and structural engineers in railway industry.

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Keywords: Prestressed concrete sleepers; structural behaviour; web opening; hole; static; performance

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1. Introduction

Railway sector is an outstanding mode of transport among the most essential and broadly utilized methods for transportation, conveying cargo, passengers, minerals, grains, and so forth. Railway prestressed concrete sleepers have been used in railway industry for over 55 years [1,2]. The railway sleepers (or called 'railroad ties') are a main component of railway track structures. The sleepers can be manufactured using timber, concrete, steel or other engineered materials [3-4]. Concrete sleepers were initially installed on track for many decades ago and at present are being used in almost everywhere in the world. Their major role is to redistribute wheel loads from the rail feet to the supporting ballast bed. Railway track structures are often subjected to impact loading conditions owing to wheel/rail interactions with common defects in either a wheel or a rail [5-7]. In addition, railway track components are often being modified at construction sites to fit with signalling gears, cables, and additional train derailment protections, such as guard rails, check rails, Earthquake protection rails, etc. There exists no practical guideline or method for sleeper retrofit and most attempts were carried out based on experiences. Even though such retrofitting task is very common in practice, the structural behaviour of holes and web openings on concrete crossties has not been well documented in open literature. As a result, it is important to understand both static and dynamic behaviours of the railway concrete sleepers with holes and web openings [8-9]. The insight into static behaviours will not only result in a safer and more reliable design method for railway infrastructure, but it can also translate and apply to other civil concrete structures.

Nomenclature

κ	curvature
d	diameter of hole or web openning
d_c	depth of sleeper at centre
d_r	depth of sleeper at railseat
g	rail gauge
l	total length of sleeper
m	mass of sleeper
w_c	width of sleeper centre
w_r	width of sleeper railseat

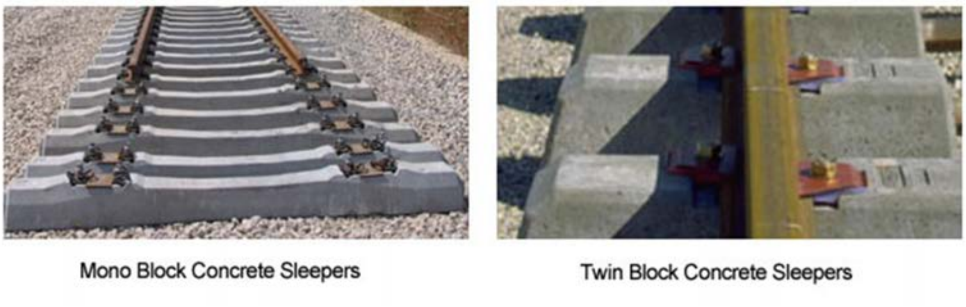

Fig. 1. Mono-block and twin-block concrete sleepers [10].

2. Significance and originality

Railway concrete sleepers (or crossties) have been initially developed for many decades globally, and become the most popular choice everywhere in the world because of its cost efficiency, durability, maintainability and positive benefits in track stability. Their main function is to distribute loads from the rail foot to the underlying ballast bed.

Railway track structures often experience impact loading conditions due to wheel/rail interactions associated with abnormalities in either a wheel or a rail (Remennikov and Kaewunruen, 2008). As a result, its structural performance must be repetitively quantified in order to identify any potential safety hazards. Such hazards are often derived from the fact that railway track components are often modified or retrofitted at construction sites to install additional but necessary signalling gears, cables, and additional train derailment protections, such as guard rails, check rails, Earthquake protection rails, etc. The engineering guideline for crosstie retrofit has not been well established, although it is a common task in construction site. In addition, the structural behaviour of holes and web openings on concrete crossties is not available in open literature. In this manner, it is crucial to understand such behaviours of concrete sleepers after being retrofitted and modified for add-on fixture in practice [11-12]. The emphasis of this study has been placed on the static structural behaviours of the sleepers with holes and web openings. Experimental work has been carried out in order to give better evidence-based insight into the structural behaviours, improving safety and reliability of railway infrastructure, and enhancing the structural safety of other similarly retrofitted concrete structures.

3. Experimental investigations

The test setups have carried out in accordance with British Standards: BS EN 13230-2:2009 [11-12], in order to provide benchmarking type-testing results as shown in Fig. 2. Table 1 shows the dimension of sleeper specimens, supplied by NetworkRail and manufactured by CEMEX. The testing was undertaken using displacement control method at a slow load rate in order to obtain more accurate data. The test equipment is as follows:

- Strain gauges and wires at top and bottom fibre (25 mm) and strain gauge bridges;
- Load cell;
- Linear potentiometer at the neutral axis and top of the sleeper; and
- Computer and data logger (DATA LOGGER SQUIRREL 2040 USB).

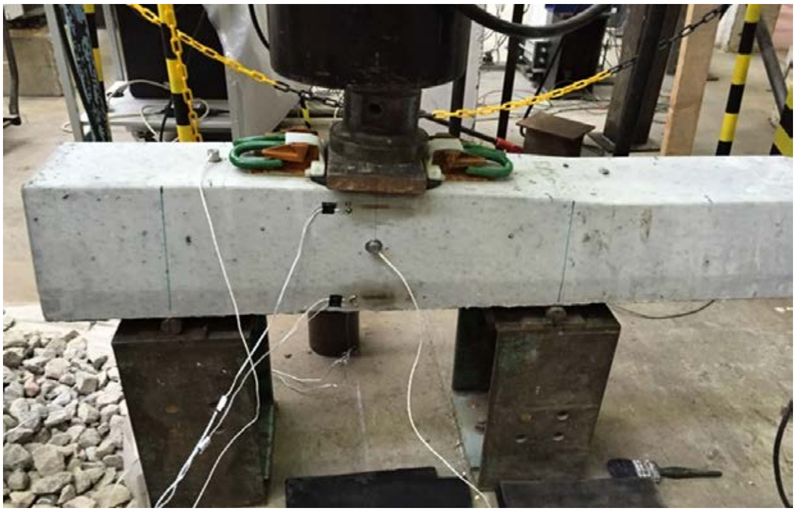

Fig. 2. Arrangement at the rail seat for positive bending test

Table 1. CEMEX sleeper properties (passenger rail network).

Mass (kg)	Gauge length (m)	Total length (m)	At railseat (m)		At centre (m)	
			w_r	d_r	w_c	d_c
312	1.502	2.520	0.200	0.200	0.285	0.175

Fig. 3 demonstrates different type of holes and web opening in concrete sleepers. Note that 32mm dimeter hole is a practical option for drilling sleepers. The maximum positive bending moments of the sleepers occur at the rail seat while the maximum negative bending moment occurs at the center of the sleeper. So, the flexure (bending) strength at rail seat is generally the most vital variable for prestressed concrete sleeper design, which is affected by practical retrofitting approach using hole and web opening. Moment-deflection curve shows a similar behaviour as load-deflection curve. It can be plotted using the data from the load-deflection curve. Maximum moment will be calculated from the maximum load obtained from the load-deflection curve. Fig. 4 demonstrates the moment-deflection comparison of the experimental results for the sleeper with and without hole and web opening.

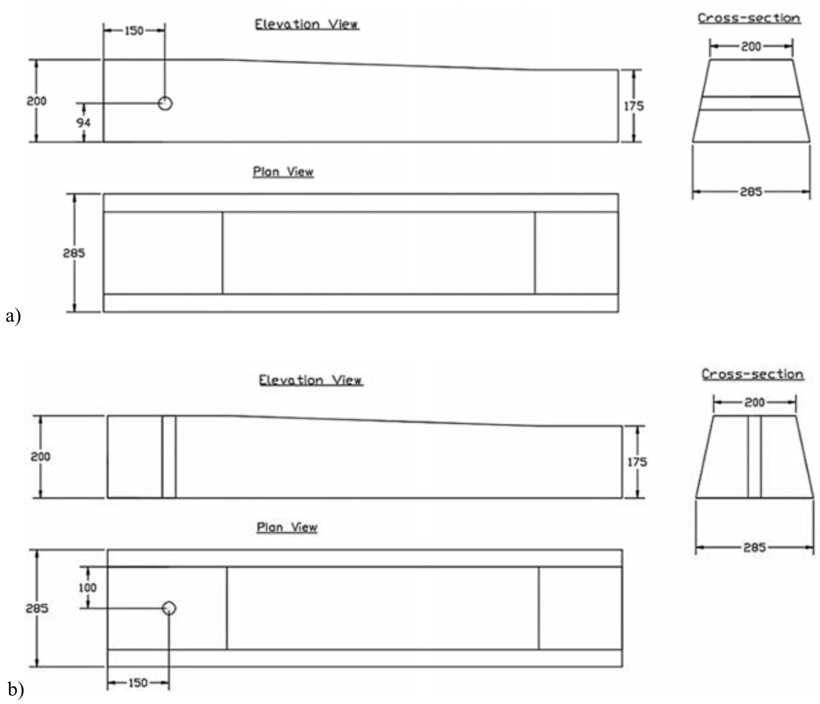

Fig. 3. Sleepers with hole and web opening, (a) transverse hole (web opening, (b) vertical hole.

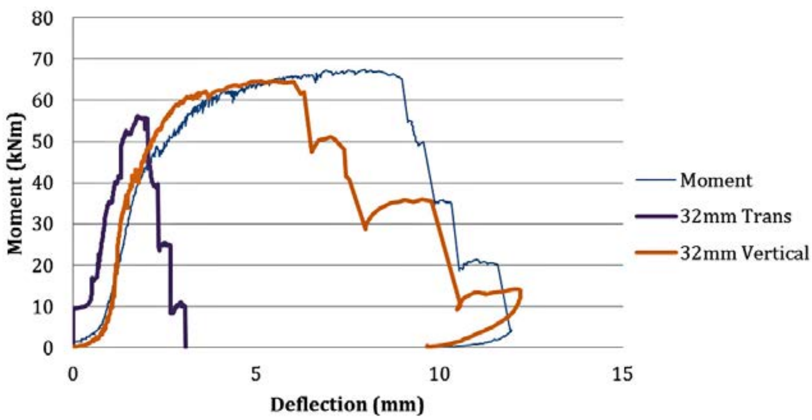

Fig. 4. Moment-deflection curve of the sleepers with and without hole and web opening.

The loading was applied at a moderate rate in order to achieve a displacement-controlled test for more accurate results [13-14]. Therefore, the crack patterns and the growth were visually observed during the testing. At the point when a crack was initially seen at first glance, corresponding load was recorded for every sleeper case. Under flexural mode, the cracks initially occurred at the bottom fibre of the sleeper due to the exceeding of the tensile strength of the concrete and spread towards the top fibre where the compression zone lies. Furthermore, the sudden reduction of the load or moment capacity shown in Fig. 4 illustrates the brittle failure of concrete where the rest of the small changes of the loads are due to steep strand snaps. It was likewise observed that the diameter of the hole does not affect the crack pattern very much. For every sleeper case with different diameters, there is a comparable crack patterns. Therefore, one-before and after-load cracking pattern has been presented for the sleepers with holes and web openings as shown in Fig. 5.

a) sleeper with no web openings before loading

b) Sleeper with no web openings after loading

c) Sleeper with transverse hole before loading

Fig. 5. Crack growth of the sleepers with and without hole and web opening.

d) Sleeper with transverse hole after loading.

e) Sleeper with vertical hole before loading.

f) Sleeper with vertical hole after loading

Fig. 6. Crack growth of the sleepers with and without hole and web opening.

4. Conclusions

This paper presents the world-first experimental investigations into the structural behaviours of railway prestressed concrete sleepers with holes and web openings. As a common practice, track engineers often generate holes or web openings in concrete sleepers to enable the accommodation of rail equipment cables and signalling equipment. This study aims to provide better understanding into structural integrity and moment-deformation capacity of pre-stressed concrete sleepers with and without holes and web openings. The experimental results exhibits that the sleepers with transverse hole (or web opening) are incapable of maintaining sleeper ductility. This insight helps provide decision making criteria for drilling the holes and web opening for track engineers. Future work includes the prognostic and damage identification of railway prestressed concrete sleepers using acoustic emission and modal analysis [15].

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References

[1] A.M. Remennikov, S. Kaewunruen, Experimental load rating of aged railway concrete sleepers, Engineering Structures. 76 (2014) 147-162.
[2] A.M. Remennikov, S. Kaewunruen, Determination of prestressing force in railway concrete sleepers using dynamic relaxation technique, ASCE Journal of Performance of Constructed Facilities. 29 (2015), doi: 10.1061/(ASCE)CF.1943-5509.0000634.
[3] Esveld, C., *Modern Railway Track*, The Netherlands MRT Press, 2001.
[4] S. Kaewunruen, A.M. Remennikov, Reliability assessment of railway prestressed concrete sleepers, Proceedings of the 2008 Australasian Structural Engineering Conference, Melbourne, Australia, June26-27, 2008.
[5] A.M. Remennikov, S. Kaewunruen, "A review on loading conditions for railway track structures due to wheel and rail vertical interactions," *Structural Control and Health Monitoring*, 15, 2008, pp. 207-234.
[6] S. Kaewunruen, A.M. Remennikov, "Dynamic crack propagations of prestressed concrete sleepers in railway track systems subjected to severe impact loads," *ASCE J of Structural Engineering*, 136(6), 2010, pp. 749-754.
[7] S. Kaewunruen, A.M.Remennikov, "Progressive failure of prestressed concrete sleepers under multiple high-intensity impact loads," *Engineering Structures*, 31(10), 2007, pp. 2460-2473.
[8] E.K. Gamage, S. Kaewunruen, A.M. Remennikov, "Design of holes and web openings in railway prestressed concrete sleepers", Railway Engineering Conference, June 28-July 2, 2015, Edinburgh.
[9] A.M. Remennikov, M.H. Murray, S. Kaewunruen, "Conversion of AS1085.14 for railway prestressed concrete sleeper to limit states design format," *AusRAIL Plus 2007*, Dec 2-6, Sydney, Australia, [CD-Rom], 2007.
[10] Wikipedia, Railroad tie, Access Online, April 2016, [https://en.wikipedia.org/wiki/Railroad_tie]
[11] British Standard, *Railway applications. Track. Concrete sleepers and bearers. Prestressed monoblock sleepers*: BSI. 32, 2009.
[12] A.M. Remennikov, M.H. Murray, S. Kaewunruen, "Reliability based conversion of a structural design code for prestressed concrete sleepers," *Proceedings of the Institution of Mechanical Engineers: Part F Journal of Rail and Rapid Transit*, 226(2), 2012, pp. 155-173.
[13] M Vu, S Kaewunruen, M Attard, Nonlinear 3D finite element modeling for structural failure analysis of concrete sleepers/bearers at an urban turnout diamond, in Handbook of Materials Failure Analysis with Case Studies from the Chemicals, Concrete and Power Industries, Elsevier, Amsterdam, 2016, doi: 10.1016/B978-0-08-100116-5.00006-5
[14] S Kaewunruen, AM Remennikov, MH Murray, Introducing a new limit states design concept to railway concrete sleepers: An Australian experience, Frontiers in Materials 1, 8, doi: 10.3389/fmats.2014.00008.
[15] S Kaewunruen, E.K. Gamage, AM Remennikov, Modelling railway prestressed concrete sleepers (crossties) with holes and web openings, Procedia Engineering, 2016 (accepted).