Peer-reviewed version available at Infrastructures 2017, 2, 3; doi:10.3390/infrastructures2010003

Technical Note

Toughness of Railroad Concrete Crossties with Holes and Web Opening

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Abstract: Prestressed concrete sleepers (or railroad ties) are principally designed in order to carry wheel loads from the rails to the ground of railway tracks. Their design takes into account static and dynamic loading conditions. In spite of the most common use of the prestressed concrete crossties in railway tracks, there have always been many demands from rail engineers to improve serviceability and functionality of concrete crossties. For example, signaling, fiber optic, equipment cables are often damaged either by ballast corners or by tamping machine. There has been a need to re-design concrete crosstie to cater cables internally so that they would not experience detrimental or harsh environments. Also, many concrete crossties need a retrofit for automatic train control device and similar signaling equipment. In contrast, the effects of holes and web openings on structural capacity of concrete crossties have not been thoroughly investigated. This paper accordingly highlights the effect of holes and web openings on the toughness and ductility of concrete crossties. The outcome of this research enables better decision making process for retrofiting prestressed concrete crossties with holes and web opening in practice.

Keywords: Concrete sleeper; crosstie; design standard; holes; web opening; railway infrastructure; static performance

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1. Introduction

Railroad is a standout amongst the most essential and broadly utilized method for transportation, conveying cargo, passengers, minerals, grains, and so forth. Railway prestressed concrete crossties have been utilized in railway industry for over 50 years [1-3]. The railroad ties (called 'railway sleepers') are a main part of railway track structures. The crossties can be made of timber, concrete, steel or other engineered materials [4]. Concrete crossties were initially introduced around many decades ago and at present are introduced in almost everywhere in the world. Their major role is to distribute loads from the rail foot to the underlying ballast bed. Railroad track structures often experience impact loading conditions due to wheel/rail interactions associated with abnormalities in either a wheel or a rail [1]. In addition, railroad track components are often being modified at construction sites to fit with signaling gears, cables, and additional train derailment protections, such as guard rails, check rails, Earthquake protection rails, etc. The practical guideline for crosstie retrofit has not been well established and many attempts were carried out based on trials and errors. Despite a common task in construction site, the behavior of holes and web openings on concrete crossties has not been well documented in open literature. In this manner, it is important to ensure that concrete crossties can be retrofitted and modified for add-on fixture in practice. The emphasis of this study has been placed on the energy toughness of the crossties with holes and web

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 August 2016 doi:10.20944/preprints201608.0047.v1

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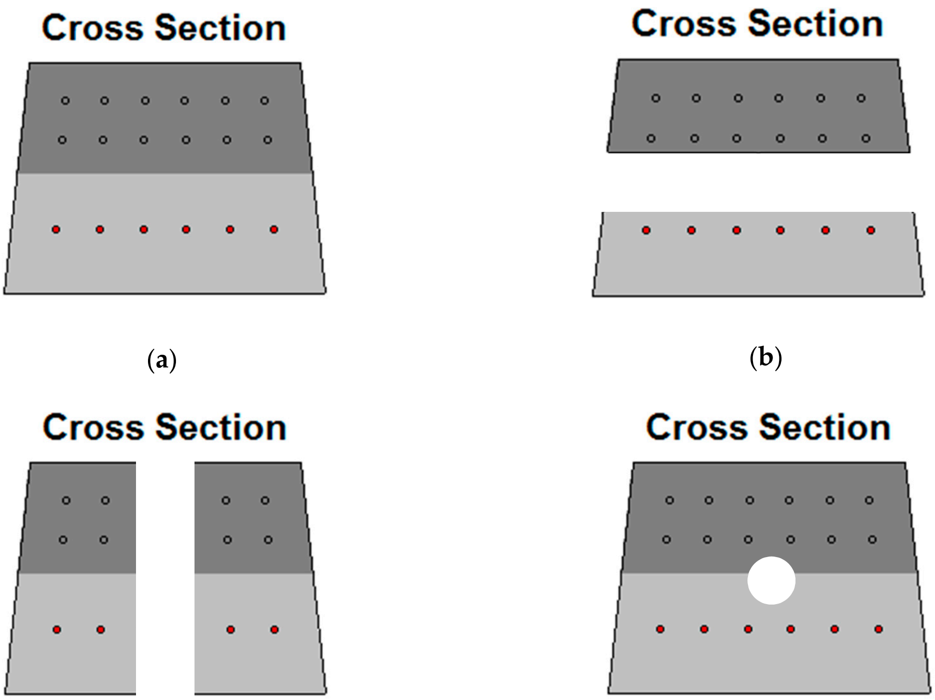
openings. The insight into these behaviors will not only improve safety and reliability of railway infrastructure, but will enhance the structural safety of other concrete structures.



(a) (b) (c) (d)

Figure 1. Web opening and holes in crossties in practice: (**a**) Full cross section of a traditional standard-gauge railway concrete crosstie; (**b**) Web Opening (or transverse hole); (**c**) Vertical hole; (**d**) Longitudinal or through hole. These holes are often installed after construction to accommodate various needs such as cables, additional bolts, bracing system, lateral or third rail fixtures, etc. The position of the hole is often at the middle between the edge of rail and the sleeper end (with reduction to about the half of maximum shear force action). No steel reinforcement has been damaged from these holes and web opening.

(a) (b)

Figure 2. Needs for modification to suit cables and pipes **(a)**; and advanced signaling systems **(b)**.

2. Experimental Evaluation

The holes and web openings are generated using a high speed coring machine on full-scale crossties. Common types of holes and web openings in practice have been carried out including the

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vertical and longitudinal holes as well as the lateral through hole, as illustrated in Figure 1, in order to accompany other systems needs as demonstrated in Figure 2. For practicality, 42mm diameter holes have been cored in a similar manner as in an actual construction. Then, they are tested under the prescribed static testing condition in order to identify the comparable and repeatable residual energy toughness [5]. Through the static tests, the load carrying capacity is plotted against railseat deflection. The fracture toughness can subsequently be identified by the integration (area under the curve) of load-deflection relationship [6]. The comparative index is a ratio between the toughness with and without holes.

In general, full load deflection curve can be found in Figure 3. The first stage of the curve is elastic stage when materials behave linearly in elastic range. Then, the nonlinear behavior takes place when the principal stress reaches the proportional yield stress and the materials make use of the nonlinear portion of the strength. Until the structural member reaches ultimate capacity or stability failure, the nonlinear portion dominates. At the ultimate point, the load deflection curve drops at certain extent due to the yielding of high strength strands and the spalling of concrete. The strength beyond this ultimate capacity, if the member is further loaded, is referred to as the residual fracture toughness in the post failure mechanism. The post failure mechanism can be clearly seen in Figure 3. It exhibits that the strands still provide the strength hardening effects to the residual load carrying capacity and the energy absorption mechanism until they reach the rupture capacity. The hardening effect is significant when more tendons remain and the effect decreases as the remaining number of tendons diminishes [7-8].

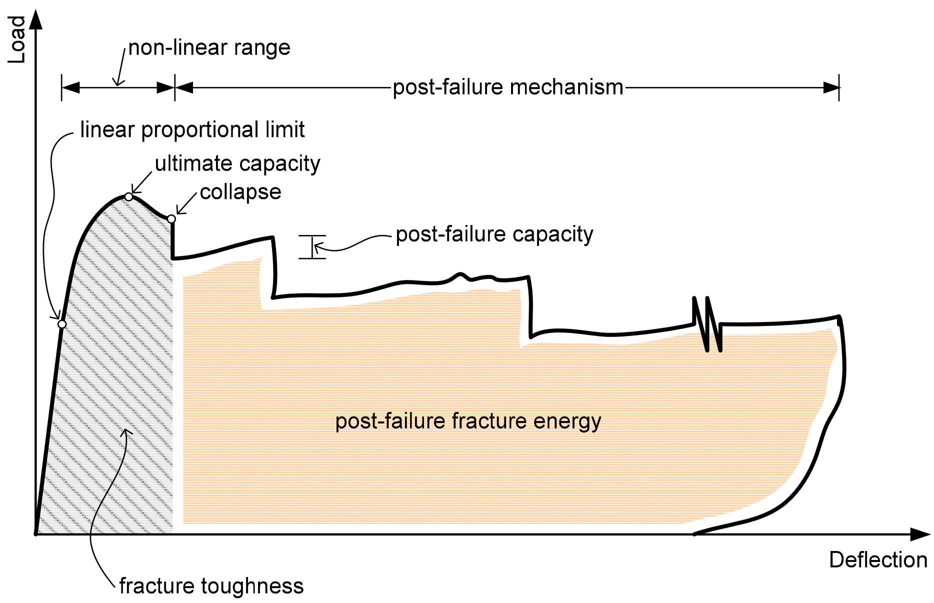

Figure 3. Schematic full load-deflection curve of structural member.

3. Results

The holes and web openings are established on full-scale concrete crossties using a high-speed diamond-coring machine in order to minimize micro cracking in concrete. Common types of holes and web openings in practice are about 40mm diameter, which is sufficient for fitting industrial cables and rods. Critical locations have been chosen based on earlier numerical studies using a finite element package ABAQUS [9-12]. The static tests have been carried out in accordance with BS EN13230 for benchmarking purpose [5]. The results reveal a very interesting behavior of the crossties with holes and web openings. Table 1 shows the ultimate moment capacities of the crossties. The failure mode analysis has been evaluated from crack propagation. It is found that the sleepers with full cross-section and with a vertical hole exhibit a bending mode of failure. We found that there were some snaps of prestressing tendons (tendons reach their characteristic yielding stress) and the first bending cracks can be observed. We can also observe that the sleepers with

 doi:10.20944/preprints201608.0047.v1

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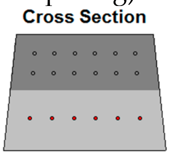
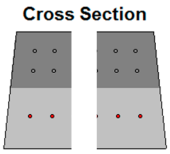
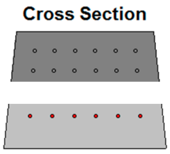
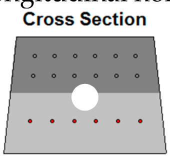
longitudinal and transverse holes failed by mixed shear and bending mode. Using load-deflection methodology, the toughness of the crossties has been evaluated as shown in Figure 4. The ductility index has been derived from the ratio of ultimate displacement over the displacement at maximum moment. It is evident that holes and web opening generally undermine the maximum strength of concrete crossties. It can be observed that the first cracks developed in the crosstie without hole and those with vertical and longitudinal holes are bending cracks. It is important to note that the crossties failed in bending. In contrast, it is found that the crosstie with transverse hole failed in shear, and diagonal cracks developed through the hole.

From Figure 4, it exhibits that the crosstie with transverse hole can absorb the least energy toughness. This also corresponds well with the ductility index results, showing that the crosstie with transverse hole failed suddenly at a brittle shear mode. In addition, it is important to note that the concrete crossties with vertical and transverse holes tend to have relatively low ductility, resulting in lesser early warning of structural failure.

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Crossties	Maximum moment capacity, kN.m	Failure mode
Intact (no holes or web opening) 	68 (100%) Bending failure	
With 42mm diameter vertical hole 	61 (90%) Bending failure	
With 42mm diameter transverse hole 	56 (82%) Mixed bending-shear failure	
With 42mm diameter longitudinal hole 	61 (90%) Mixed bending-shear failure	

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4. Discussion

In practice, quasi-static design and analysis is adopted in a similar way of testings to simplify the process. At present, the static performance of concrete crossties or sleepers with holes and web opening cannot be realistically estimated [12-15]. This research work is a fundamental step to achieve better insight into the behavior and durability of concrete crossties with holes and web opening. Our experimental results based on industry practice reveal that the transverse and longitudinal holes shift the mode of failure from bending to shear-bending. This implies that the application of transverse and longitudinal holes in concrete crossties could affect longer term performance in dynamic conditions, when large deformation of crossties cannot be observed prior to brittle shear-bending failure mode. Such the action will yield very little early warning before structural failure. As a result, it is very important to track engineer to restrict or minimize the use of these holes.

Based on our experimental results, we also found that the strength of materials is very consistent with standard variation of less than 3%. This significance underpins our confidence in the experimental results with limited number of samples. However, it is very important to note that we have studied for only the cases of industrial practice. Smaller size of holes and web opening (<25 mm diameter) may yield better results. We will investigate this issue further using numerical simulations in the future, in order to evaluate the size effect and the crosstie behavior under impact loadings.

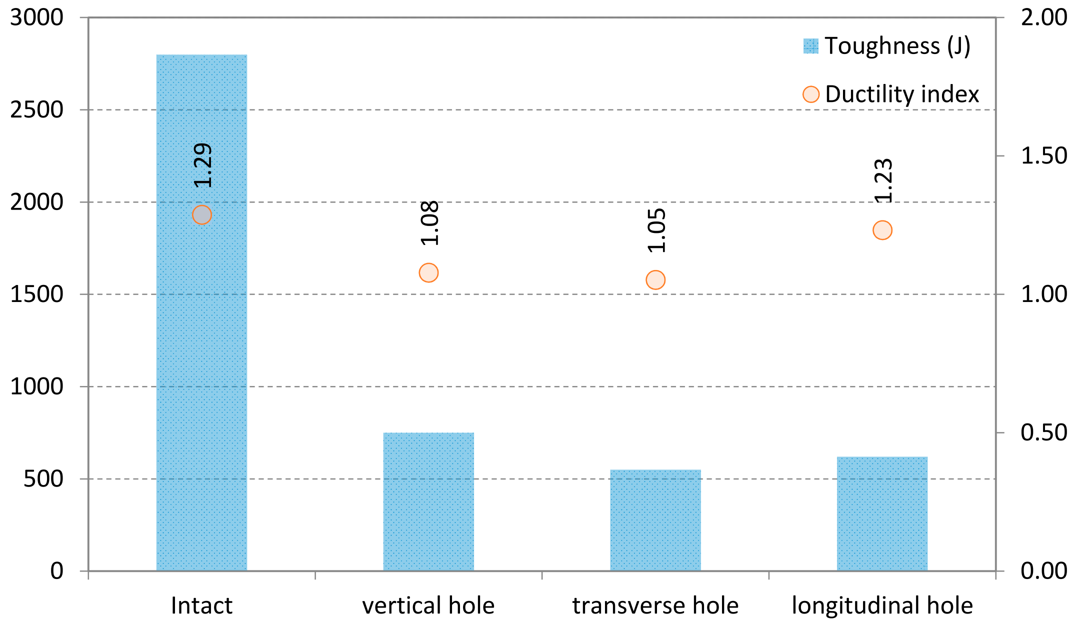

Figure 4. Toughness of railroad concrete crossties with holes and web opening.

5. Conclusions

The holes and web openings undermine strength, toughness and ductility of railroad concrete crossties. It is essentially important for track and rail engineers to assure that the modification or retrofitting of concrete crossties at construction sites is carried out in a proper manner. By the results obtained from these unprecedented full-scale experiments, it is recommended that transverse hole should be particularly avoided. This is because the transverse hole can reduce almost 20% of load bearing capacity of the crosstie and such the hole also results in significant reduction of energy toughness and importantly ductility. The insight into structural behavior of the concrete crossties with holes and web opening will enable safer built environment in railway corridor, especially for concrete crossties whose structural inspection is very difficult in practice.

Acknowledgments: The authors would also like to thank British Department of Transport (DfT) for Transport - Technology Research Innovations Grant Scheme, Project No. RCS15/0233; and the BRIDGE Grant (provided by University of Birmingham and the University of Illinois at Urbana Champaign). The second author is gratefully acknowledge the Japan Society for the Promotion of Science (JSPS) for his JSPS Invitation Research Fellowship (Long-term), Grant No L15701, at Track Dynamics Laboratory, Railway Technical Research Institute and at Concrete Laboratory, the University of Tokyo, Tokyo, Japan.

Author Contributions: E.K.G. and S.K. conceived and designed the experiments; E.K.G. and S.K. performed the experiments; E.K.G. and S.K. analyzed the data; A.M.R. and T.I. contributed reagents/materials/analysis tools; everyone wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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