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Review of Failures of Railway Sleepers and its Consequences

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ABSTRACT

Railway sleeper is one of the important structure that having problems with high maintenance and replacement costs owing to its early failure. This paper presents the causes of failures of the traditional railway sleepers particularly timber, concrete and steel, and discussed its effect on the railway industry. The review of literature indicates fungal decay, end splitting and termite attack are the typical causes of timber sleeper failure. In case of concrete sleeper, deteriorations are observed because of rail seat abrasion, longitudinal cracking, high impact force and chemical attack. Failures in steel sleepers are mainly due to corrosion and fatigue cracking at the rail seat region. These unexpected failures of sleeper significantly increase the track maintenance costs. This paper also presents some recommendations to minimise sleeper failures for their safer usage.

KEYWORDS: Railway sleeper, Causes of failure, Protective measures

1.0 INTRODUCTION

Australia has one of the longest railway networks in the world. Timber, concrete and steel are the existing primary materials for railway sleepers which have targeted life spans of 20, 50 and 50 years respectively. However, these traditional sleepers have not satisfactorily met the performance requirements due to their unexpected early failures under certain circumstances and in particular environments. The problems of timber rotting, splitting and being infested with insects, as well as its scarcity, became a new challenge which led to the use steel and concrete. Steel’s risk of corrosion, high electrical conductivity, fatigue cracking in the rail seat region and the difficulty of packing it with ballast has made it an inferior material to be used in sleepers. On the other hand, prestressed concrete sleepers, which offer greater durability than timber and steel, suffer from heavy weight, high initial cost, low impact resistance, susceptibility to chemical attack and consequently have failed to satisfactorily meet demands. Millions of sleepers are manufactured every year to satisfy demand for network expansions and line upgrades. Approximately three billion sleepers are currently used in rail networks around the world (FIB, 2006). Over 400 million of these sleepers are made from concrete and 2 to 5% of them require replacement every year due to their premature failure (Palomo et al. 2007). It has been reported that over 12 million timber sleepers are replaced every year in the USA at a cost of around 500 million dollars (Qiao et al. 1998) while another report indicates that the cost of sleeper renewal is about 12% of the total maintenance-of-way cost, that is, approximately twice that of the rail renewal (Magee, 1950). Research and innovation are now focusing on the durability of sleepers as the lack of understanding of sleeper degradation mechanisms is a great concern (Zhang et al. 1997). This paper presents the failure mechanisms in traditional railway sleepers and suggestions for minimising them for maintaining lower maintenance cost and to provide useful information to engineers, designers as well as asset owners.
2.0 COMMON TYPES OF SLEEPER FAILURE

2.1 *Timber sleeper*

The survey conducted by the Railway of Australia (ROA) (Hagaman and McAlpine, 1991) indicated that the principal causes for timber sleeper failures are fungal decay, end splitting and termite attacks which are responsible for 53, 10 and 7% of failures respectively are discussed below. Beside those failures they found some other modes of deterioration of timber sleeper but their possibility of occurrence is relatively lower.

**Fungal decay**

Fungal decay is considered as the predominant mode of timber sleeper failure (Fig. 1). During rainy seasons the sleeper can absorb moisture that makes fungi reactive. It can spread from one location to another across non-nutritional surfaces that adversely affect a track’s structural integrity (Singh, 1999).

![Fig. 1: Failure of timber sleeper due to fungal decay (Manalo et al. 2010)](image)

**End splitting**

Splitting at the end of timber sleeper arises when the sleeper is subjected to large transverse shear loading (Manalo et al. 2010; Hibbeler, 2004). Also the sleeper may split during insertion of screw-spike for the fastening system. Figure 2 showed the timber sleeper deterioration due to end splitting.

![Fig. 2: End splitting of timber sleeper](image)
**Termite attacks**

Termite attacks in timber sleepers have been identified as another significant cause of sleeper damage and it has been reported that the worldwide cost of repairing structures and preventing these attacks is approximately one billion dollars annually (Ahmed and French, 2005). Termites live in colonies and build their nests in timber and consume all the cellulose-containing materials when it attacks in timber even after treatment with creosote (Fig. 3).

![Termite attacks in timber sleeper](usda2003.png)

**Fig. 3: Termite attacks in timber sleeper (USDA, 2003)**

2.2 **Concrete sleeper**

Over the last three decades, researchers in different parts of the world have been investigating the failures of concrete sleepers. The major failures are discussed in the next sections.

**Rail-seat deterioration**

Rail-seat deterioration is the most common mode of concrete sleeper failure. This failure is caused either by rail-seat abrasion, hydro abrasive erosion, hydraulic pressure cracking, freeze thaw cracking or chemical deterioration (Bakharev and Struble, 1997) of which rail-seat abrasion is the most critical. Rail-seat abrasion occurs due to the relative movements between the rail pad and concrete rail seat which subsequently resulting in the gradual wearing away of the cement paste from the concrete by frictional forces as the abrasive fine particles and the water penetrates the rail-seat pad interface creating an ideal situation for abrasion showed in Figure 4.

![Failure of concrete sleeper due to rail-seat abrasion](zemanea.png)

**Fig. 4: Failure of concrete sleeper due to rail-seat abrasion (Zeman et al. 2009)**
Longitudinal cracking

The study conducted by Rezaie et al. (Rezaie et al. 2012) found severe damage in a sleeper caused by longitudinal cracking which was observed even before the sleeper was mounted in a railway track. A remarkable tensile stress was generated in the transverse direction around bolt-hole due to pre-tension forces and cracking occurred at that location. During its service life, additional effects such as water freezing and the existence of fine rocks within its rawlplugs can lead to increases in the transverse tensile stress in a sleeper and cause longitudinal cracks to appear (Fig. 5). Similar conclusions were drawn by Ma et al. (Ma et al. 2010) who found that the high shearing tensile stress on the edge of the bolt hole is the main cause of longitudinal cracks in a sleeper.

![Fig. 5: Longitudinal cracking due to tensile stress between rawlplugs (Rezaie et al. 2012)](image)

Cracking due to impact loading

The impact loading on railway sleeper can arise by either wheel or rail abnormalities, such as flat wheels and dipped rails. This kind of loading is very infrequent but high-magnitude with short duration (Murray and Cai, 1998; Remennikov and Kaewunruen, 2007). A field investigation into passenger lines as well as coal/mine transport in the Wollongong railway’s suburban network confirmed that a crack in a sleeper occurred because of the effect of impact loading (Fig. 6).

![Fig. 6: Cracks in concrete sleepers due to impact loading (Kaewunruen and Remennikov, 2008)](image)

Cracking due to chemical attack

The ordinary cement concrete is vulnerable to chemical attack caused by different salts. Soil, groundwater and sometimes aggregates may contain sulfates of sodium, potassium, magnesium and calcium which, when present in a solution, react with the tricalcium aluminate or calcium hydroxide
components of the cement paste. Such reactions cause expansion which leads to cracking and, finally, deterioration of the concrete (Narayanan and Beeby, 2005; Neville, 2012). The cracking of prestressed concrete sleeper due to the internal sulphate attack which is commonly known as delayed ettringite formation (DEF) was investigated by Tepponen and Eriksson (Tepponen and Eriksson, 1987) who noted the damage occurred in concrete sleeper in Finland within 10 years after its manufacture. Hime’s (Hime, 1996) investigation also confirmed that the cracking of prestressed concrete sleepers due to delayed ettringite formation may come after they have been in service for several years. Similar failure noticed by Sahu et al. (Sahu and Thaulow, 2004) in Swedish concrete sleeper (Fig. 7a). However, the concrete sleeper may crack due to the other types of chemical attack. Shayan et al. (Shayan and Quick, 1992) investigated the causes of parallel longitudinal cracking on the top surfaces and map cracking at the ends of prestressed concrete sleepers by examining both cracked and uncracked sleepers which showed that the alkali-aggregate reaction (AAR) is responsible for sleeper failures (Fig. 7b).

![DEF cracking](image1.jpg)  ![AAR cracking](image2.jpg)

(a) DEF cracking (Sahu and Thaulow, 2004)  (b) AAR cracking (Fournier et al. 2004)

Fig. 7: Cracking of prestressed concrete sleeper

2.3 Steel sleeper

In Australia, approximately 13% of sleepers used in tracks are manufactured by steel which is also suffering from premature deterioration. A very limited research conducted on the failure of steel sleeper. Steel’s risk of corrosion and fatigue cracking has been identified the primary causes of steel sleeper failure.

**Failure due to corrosion**

Steel sleepers may come into contact with different salts from soil, groundwater or aggregates which can react with steel, leading to sleeper failure due to corrosion (Fig. 8). Using metallic slag-based ballast or the presence of corrosive materials in the rail track may also corrode steel sleeper.
Failure due to fatigue cracking

The rail-seat location of sleeper is subjected to heavy shear because of the repeated stress imposed by cyclic loading. When a train is running over rails, as a sleeper experiences both longitudinal and transverse stresses, a diagonal stress originates its rail-seat location which is usually on its top surface but can also occur in the reverse direction depending on the train’s movement and, over time results in fatigue cracking (Langman, 1983).

3.0 TECHNIQUES FOR MINIMISING FAILURE

Different approaches for minimising sleeper failures have been conducted and some of them already implemented. The following section discusses those techniques to provide guidelines for scientific researchers and practicing engineers.

3.1 Timber sleeper

Fungus and termite attacks in timber structures can be controlled by impregnation with synthetic chemicals and biological protection techniques. The toxic chemical usually used in chemical protection method which can destroy the harmful organisms in timber. Recently, Verma et al. (Verma et al. 2009) and Susi et al. (Susi et al. 2011) have been emphasising the use of biological wood protection methods in order to address public concerns and conform to new environmental regulations regarding the use of chemicals. These methods involve placing micro-organisms in materials which prevent attacks by species but do not affect the materials’ properties.

To reduce the splitting of timber sleeper, plates (Fig. 9) can be fixed at its ends to minimise separation (Conners, 2008; ARTC, 2011). However this technique only works when the splitting width and length is small, usually no more than 20 mm and 250 mm, respectively. For unseasoned and seasoned sleepers, the accepted limits for the splitting width are 3 mm and 6 mm and, for length 100 mm and the width of the sleeper respectively. Therefore, sleepers which are beyond their acceptance limits but not more than 20 mm in width and 250 mm in length could be saved by providing end-plates.
3.2 Concrete sleeper

The rail-seat deterioration and cracking are the two major problems for concrete sleeper. Many studies have been conducted for preventing rail-seat deterioration. Peters et al. (Peters and Mattson, 2004) attempted to minimise abrasion using cast-in-place steel plates that covered the rail-seat area. Their experimental investigation confirmed their effectiveness against abrasion control but the additional cost associated with steel plate is a major concern. Another approach for preventing abrasion was studied by Peters (Peters, 2007) in which the researcher applied an epoxy coating over the rail-seat region. However, it is not a very convincing option as it is labour intensive, requires track closures during the application and curing of the epoxy, and there is a possibility that the epoxy will wear away over time. Alternative preventive measures considered by researchers include: the addition of fly ash and silica fume to the concrete in the rail-seat (Shurpali et al. 2013); the introduction of steel fibre-reinforced grout in the rail-seat region during manufacturing (Peters and Mattson, 2004; Takahashi, 2008); the application of multi-layer abrasion-resistant pad assembly (Peters and Mattson, 2004); and placing metallic aggregates in the rail-seat area (Wu et al. 2001). In 2002, Atis (Atis, 2002) showed that concrete with a high-volume of fly ash has better abrasion-resistant properties and suggested using it in areas where highly abrasion-resistant concrete is required.

Longitudinal cracking in concrete sleeper occurs due to the high shearing tensile stress around the bolt hole, and to minimise it, Ma et al. (Ma et al. 2010) suggested redistributing it by the use of a special expansive concrete in the inner and ordinary concrete in the outer parts of the bolt-hole area which will produce a radial nested stress on the interface between the two parts through expansion of the inner part and, finally, achieve a significant reduction of the shearing tensile stress. Another method for controlling longitudinal cracks suggested by Rezaie et al. (Rezaie et al. 2012) is to place transverse reinforcing bars in a sleeper, especially around the rawlplug hole to strengthen the sleeper transversely and sustain more inducing pressure which can change the directions of the cracks and cracking planes.

3.3 Steel sleeper

Corrosion in steel sleeper can minimise by taking some special cares. The Australian Rail Track Corporation (ARTC) suggested avoiding the use of steel sleepers in locations where the ballast is made from slag, there is high salinity, such as coastal regions, continually moist areas and areas with corrosive materials, such as coal, minerals, mud, clay and dirt (ARTC, 2009). Creating a protective layer over steel sleeper is another useful method to prevent corrosion (Chaudhary, 2003) and zinc (Zn) coating have been using for this purpose.

4.0 CONCLUSIONS

This paper highlighted the different failure modes and the preventive measures of traditional railway sleepers from which the following conclusions are drawn.
- Fungal decay, end splitting and termite attacks are the most common modes of timber sleeper failure which is responsible for 53%, 10% and 7% of them respectively. Impregnation with synthetic chemicals and biological treatment protects timber sleeper from fungal decay and termite attacks, whereas, providing end plates is effective for controlling end splitting.
- Rail-seat deterioration and cracking are the two major modes of concrete sleeper failure. The rail-seat deterioration can be minimised by applying steel plates, epoxy coating, fibre-reinforced grout, multilayer abrasion-resistant pad or metallic aggregates at the rail-seat area. On the other hand, longitudinal cracking can be controlled by introducing a special expansive concrete around the bolt-hole area while transverse reinforcing bars can be placed in it, especially around the bolt hole, to strengthen it transversely.
- Corrosion in steel sleeper is one of the principal causes of their failure. Steel sleepers are not to be used in locations where ballast slag, high salinity, moist environment and corrosive materials are common. Zinc coating can be applied to create a protective layer on steel against corrosion.

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