Performance of Rail Ballast Stabilized with Resilient Rubber Pads Under Cyclic and Impact Loading

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ABSTRACT: Although railroads are one of the most popular modes of transportation in countries such as Sri Lanka, Australia, and USA, their rapidly growing populations and increasing congestion in road transport has created severe challenges to the sustainability of rail transport infrastructure, which in turn increases the demand for high speed and heavy-haul trains. Ballast is the foundation material beneath concrete sleepers that provides key structural support against the high dynamic loading exerted by moving trains. However, the degradation of ballast seriously affects track stability and longevity. In recent years the use of resilient rubber pads has become increasingly popular. In this study, large scale cyclic and impact load tests were performed at the University of Wollongong to understand performance of ballast and the subsequent mitigation of ballast degradation using resilient rubber pads. The test results confirm that the use of resilient pads significantly reduces the ballast deformation and degradation due to high cyclic and impact stresses.

1 INTRODUCTION

Ballasted track is the traditional railway system where the ballast material provides structural support against the high dynamic stresses transmitted from moving trains. The ever increasing congestion in highway traffic due to the huge growth in population and rapid urbanisation has only emphasized the need for the sustainable development of railroad transportation infrastructure. Indeed, the demand for a better railway system in terms of its speed and carrying capacity is inevitable in this modern era, so in order to meet this demand, ballasted rail tracks require serious improvements.

The adoption of various forms of resilient rubber pads to improve ballasted track has become increasingly popular in recent years (Esveld, 2001; Bolmsvik, 2005; Schneider et al., 2011). These artificial inclusions are known as Under Sleeper Pad (USP) and Under Ballast Mat (UBM), and they make a relatively soft interface with the ballast and thus reduce the internal contact stresses in ballast. Currently there is no comprehensive assessment of the geotechnical behaviour of ballast under cyclic and impact loading where resilient rubber pads were used. This paper presents some of the recent research work undertaken on ballast using the state-of-the-art large scale testing facilities designed and built at the University of Wollongong, New South Wales, Australia.

2 LARGE SCALE TESTING

Ballast particles undergo progressive deformation and degradation when subjected to large and undue stresses developed by repeated cyclic loading. These cyclic stresses were simulated using the process simulation prismoidal triaxial apparatus (PSPTA) shown in Fig. 1. The area of the prototype PSPTA replicates a unit cell of standard gauge Australian heavy haul track (Indraratna et al., 2015), so it correctly simulates realistic stress and boundary conditions. In a real rail track, the lateral deformation of ballast is not fully restrained, particularly parallel to the sleepers (Indraratna et al., 2001). The vertical walls of the prismoidal chamber were built to simulate the free movement of ballast under cyclic loading.

The impact forces in rail tracks occur due to wheel-rail imperfections such as wheel flats, intersections, and turnouts. These irregularities are distinct in nature and can cause the train wheels to impact onto the rail (dynamic wheel-rail impact forces) and create a forced vibration with high frequencies (Indraratna et al., 2012; Bian et al., 2013). These forces are higher in magnitude than typical quasi-static forces and therefore accelerate ballast breakage. This problem was simulated in the laboratory using the high capacity drop weight impact test machine shown in Fig. 2.

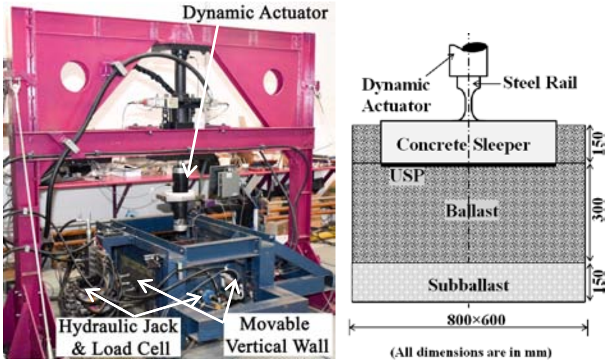

Fig. 1 Process Simulation Prismoidal Triaxial Apparatus (PSPTA) and Cyclic Load Test Specimen.

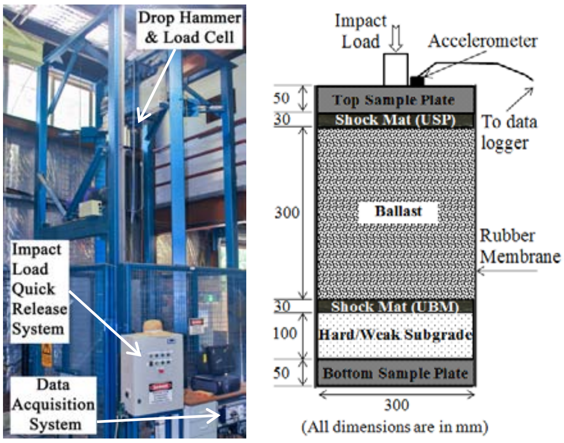

Fig. 2 High Capacity Drop Weight Impact Apparatus and Impact Load Test Specimen.

2.1 *Test Materials*

The materials used in this study were ballast, subballast, subgrade, and resilient rubber pads. The material commonly used for railway ballast in New South Wales (NSW), Australia is Latite basalt, a common igneous rock found on the south cost of NSW and closer to Wollongong City, Australia. These dark fine grained, and very dense aggregates made from crushed volcanic basalt have sharp angular corners and are therefore considered to be suitable as fresh ballast. The material was prepared in accordance with current practice in Australia. The ballast material was thoroughly cleaned with water and then dried and sieved to obtain the required particle size distribution (PSD). The PSD of fresh ballast, subballast, and sand that was used as a weak subgrade are shown in Fig. 3.

Two types of 10 mm thick resilient rubber pads were used in this study. The elastoplastic USP made from polyurethane was used for cyclic load testing. This rubber pad was attached to the bottom of the concrete sleeper when testing with USP. The recycled resilient rubber pads used for impact load testing were made of recycled rubber granulates encapsulated within a polyurethane elastomer compound. For the impact load test a layer of resilient rubber pad was used by combining three 10 mm thick pads either at the top (USP) or at the bottom (UBM) of the ballast. The mechanical properties of the resilient rubber pads are shown in Table 1. USP is generally stiffer than UBM because they are placed adjacent to higher stress zones such as the sleeper-ballast interface. However, to evaluate the relative efficiency of the resilient rubber pads, the same material type and thickness were used for USP and UBM in the impact load tests.

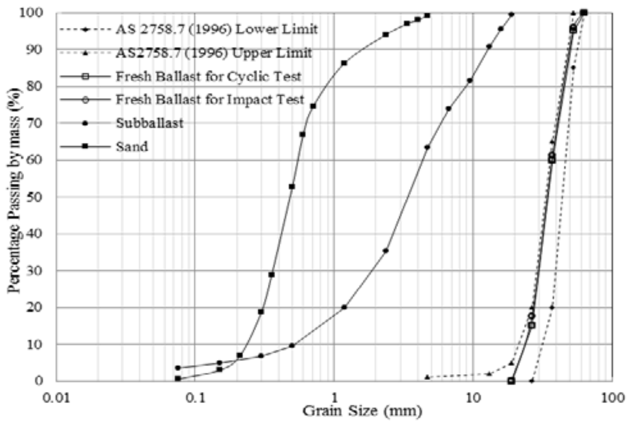

Fig. 3 Particle Size Distribution of Materials.

Table 1. Mechanical properties of resilient rubber pads

Resilient Pad (USP) for Cyclic Load Test	
Bedding Modulus	0.22 N/mm^3
Average Tear Strength at USP-Sleeper	0.5 MPa
Resilient Pad (USP & UBM) for Impact Load Test	
Young's Modulus	6.12 MPa
Tensile Strength	600 kPa

2.2 *Cyclic and Impact Loading*

The cyclic load test corresponded to a 25 ton axle load with a frequency of 15 Hz; this simulated a train travelling at about 110 km/h (Indraratna et al., 2015). The servo hydraulic dynamic actuator (See Fig. 1) can replicate the cyclic loading in a sinusoidal wave form with a mean stress of 195 kPa, and amplitude of 165 kPa. Lateral confinement was applied by hydraulic jacks through movable vertical walls that simulated a low confining stress of 10 kPa. The longitudinal directions of the walls were locked in position to ensure plane strain conditions, while the pressure exerted on the wall was measured by the load cell connected with hydraulic jacks. A total of half million load cycles were applied for each cyclic loading test.

The impact load tests were conducted by dropping a 5.81 kN (592 kg) free fall hammer onto the test specimen, as shown in Fig. 2. It was found that friction in the guiding runner increased the hammer's experimental drop height to 104% of the theoretical drop height. So the required drop height based on energy conservation theory was revised by considering the efficiency of the test rig into account (Kaewunruen and Remennikov, 2010). A load cell mounted at the bottom of the hammer was used to measure the impact force caused by the drop hammer and the ballast deformation and transient acceleration were measured by a piezoelectric accelerometer connected to the top of the sample load plate. A total of 10 impact loads were applied to each specimen.

2.3 *Sample Preparation and Test Procedure*

The PSPTA chamber can accommodate a 800×600×600 mm (length×width×height) size sample. The bottom layer of the test specimen (see Fig. 1) consisted of 150 mm thick, compacted layer of subballast. The 300 mm thick layer of ballast above the subballast was compacted by a padded rubber hammer into three equal 100 mm thick layers to achieve a typical field density of 15.3 kN/m^3. A 150 mm thick layer of crib ballast was filled around the rail-sleeper assembly and on top of the ballast layer. Tests were performed with and without the inclusion of USP.

The 300 mm diameter and 300 mm high cylindrical impact test specimens were compacted inside a 7 mm thick rubber membrane to a typical field density of 15.3 kN/m^3. Two subgrade conditions, weak and hard, were simulated by 100 mm thick compacted sand and a 50 mm thick steel plate, respectively. The material properties of subgrade have been presented elsewhere (Nimbalkar et al., 2012). The top and bottom sample plates were used to transfer the impact load to the ballast. The impact tests were conducted by placing the rubber pads at the top (USP) or bottom (UBM) of the ballast layer as shown in Fig. 2.

3 LABORATORY TEST RESULTS

The stress-strain response and degradation behaviour of the ballast with and without resilient rubber pads were analysed from the cyclic and impact tests and are discussed in the following sections. The Ballast Breakage Index (BBI) proposed by Indraratna et al. (2005) was used to analyse the extent of particle breakage during cyclic and impact loading.

3.1 *Cyclic load test*

Cyclic load test was conducted on the ballast with and without USP. The shear (ε_q) and volumetric (ε_p) strain responses were calculated from the vertical (ε_1) and lateral (ε_3) strains for a selected number of load cycles (e.g. N=100, 500, 1000, etc.). For plane strain condition (longitudinal walls were locked for movement), the shear and volumetric strain are given by (Timoshenko and Goodier, 1970),

$$\varepsilon_q = \tfrac{2}{3}\left(\varepsilon_1^2 + \varepsilon_3^2 - \varepsilon_1\varepsilon_3\right)^{1/2} \quad (1)$$

$$\varepsilon_p = \left(\varepsilon_1 + \varepsilon_3\right) \quad (2)$$

The shear and volumetric strains were reduced up to 30% by using USP under cyclic loading conditions, as is apparent from the results shown in Fig. 4. It is also evident from Fig. 4 that a rapid ballast deformation occurred up to around 10,000 load cycles and the rate of deformation decreased with increasing load cycles as the ballast mass stabilised in the later load cycles.

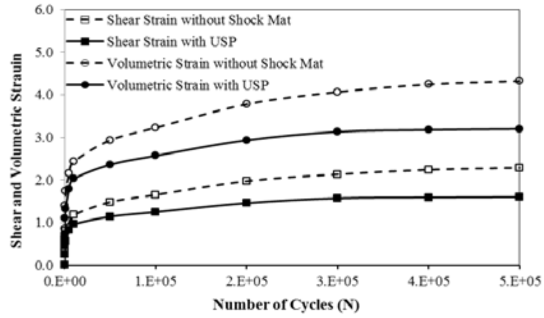

Fig. 4 Cyclic Shear and Volumetric Strain responses.

The BBI of the ballast layer was assessed with depth by analysing the layer into 3 equal 100 mm top, middle, and bottom layers. The results shown in Fig. 5 confirmed that the ballast breakages were reduced by more than 50% when USP was used.

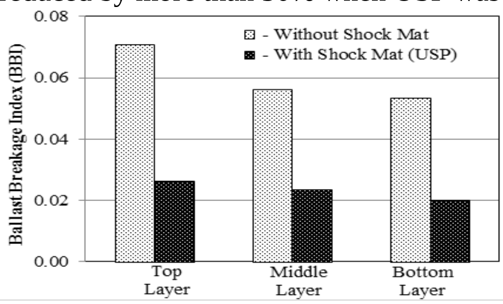

Fig. 5 Particle Breakage during Cyclic Loading.

3.2 *Impact load test*

Impact tests were conducted by placing the resilient rubber pads either at the top (USP) or the bottom (UBM), and then the results were compared to the test carried out without any resilient rubber pads. A total of six tests were conducted for two subgrade conditions (weak and hard). The shear (ε_q) and volumetric (ε_p) strains were calculated using the following equations (Timoshenko and Goodier, 1970) for axisymmetric loading and are plotted in Fig. 6 (a) and (b), respectively.

$$\varepsilon_q = \tfrac{2}{3}\left(\varepsilon_1 - \varepsilon_3\right) \quad (3)$$

$$\varepsilon_p = \left(\varepsilon_1 + 2\varepsilon_3\right) \tag{4}$$

About 45% reduction in strain was found from the results (Fig. 6) when the resilient rubber pads were placed either at the top or bottom of the ballast, and the results showed that the strains were higher when the base was a hard subgrade, such as

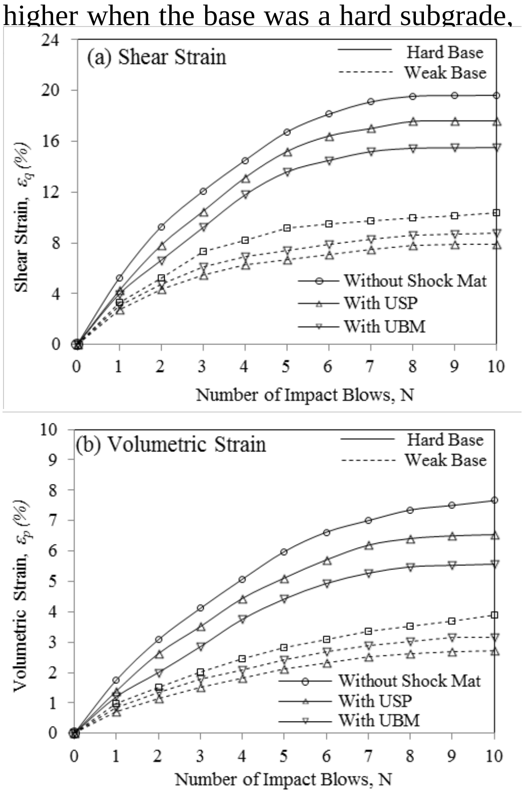

Fig. 6 Impact Load Strain Responses: (a) Shear (b) Volumetric (data sourced from Nimbalkar et al. (2012)).

The BBI also had the same trend as the cyclic test, in that the resilient rubber pads reduced ballast breakage significantly, as shown in Fig. 7. The BBI was also higher when the subgrade was hard.

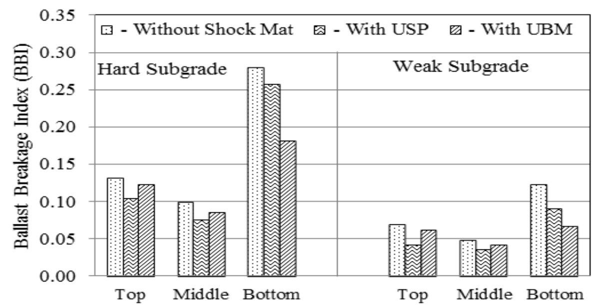

Fig. 7. Particle Breakage during Impact Loading (data sourced from Nimbalkar et al. (2012)).

4 CONCLUSIONS

This paper presents the results of state-of-the-art large scale laboratory testing conducted at the University of Wollongong to analyse the performance of ballast under cyclic and impact loading when resilient rubber pads are used. The impact loads were simulated using the high capacity drop-weight impact apparatus and the cyclic loads were applied using large-scale process simulation prismoidal triaxial apparatus. The benefits associated with resilient rubber pads such as reduced deformation and degradation of the ballast were observed under both impact and cyclic loads. The resilient rubber pads proved to be more beneficial when they were placed in a hard subgrade condition such as the rail track on a concrete bridge.

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