Dynamic responses of railway bridge ends: A systems performance improvement by application of ballast glue/bond

Sakdirat Kaewunruen

Available at: http://works.bepress.com/sakdirat_kaewunruen/46/
Dynamic responses of railway bridge ends: A systems performance improvement by application of ballast glue/bond

Sakdirat Kaewunruen

RailCorp - Transport for NSW, Level 13, 477 Pitt St, Sydney 2000 New South Wales, Australia. E-mail: sak.kaewunruen@railcorp.nsw.gov.au; and,

Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Ave, Cambridge, MA 02139-4307 USA. E-mail: sakdirat@mit.edu

Abstract

Accelerated deterioration of railway bridge approaches often induces downtime or restricted railway operation; and importantly causes more frequent maintenance, which is costly and time-consuming. Such deterioration is believed to occur because of high dynamic impact loading from the difference of stiffness between railway track and bridge and poor condition of track support at the bridge ends. The abrupt change in track stiffness often causes accelerated degradation of track geometry and components and poor ride quality, demanding higher maintenance. On this ground, there are a number of improvement programs that have been implemented in order to provide a transition to smooth the stiffness interface. In general, the transitions were designed to either:

• Provide a gradual increase in the stiffness of ballasted track to match that of the stiffer track (stiffness ramping); or
• Equalise the stiffness and rail deflection, usually by controlling the resilience of rails on the stiffer track, or by adding more resiliency to the stiffer track.

This field study demonstrates an application of ballast glue/bond to improve the smoothness of stiffness along the ballasted track at bridge ends. The method appears to be useful for brown-field maintenance where adjacent aged infrastructure exists. The ballast glue/bond could reinforce the ballasted track stiffness through the aggregate adhesion whilst the drainage property of ballast is not undermined. The field trail was conducted at a railway bridge in Windsor, NSW Australia. This paper presents the field performance and the dynamic behaviour and responses of railway bridge ends improved by the ballast glue/bond. The results show that the ballast glue/bond suppresses vibrations at high frequencies but excites the track resonances at low frequency range. After one year revenue services, the field survey investigation indicates the stability of track geometry at the bridge end systems.

Keywords: railway bridge end, railway maintenance, bridge approach, ballast glue, ballast bond, dynamic responses, vibration suppression, track-bridge systems.
1 Introduction

The transition from ballasted track forms to non-ballasted trackforms or structures often causes a high rate of track deterioration due to the dynamic impact excitation by the abrupt change of track stiffness. This results in accelerated rates of track geometry and component degradation, high maintenance need, poor ride comfort, and high fatigue stress threshold for passing rolling stocks. As a result, a number of bridge end improvement methodologies have been implemented around the world in order to mitigate such problem.

Engineering Standards (i.e. ESC 310 Underbridge in Australia) have suggested several methods to provide stiffness transition, which depends on the brown-field situations of renewal or construction work at a particular location [1]. A criterion for the stiffness transition is to smooth the stiffness interface between the dissimilar track types.

Feasible options are to design the transition to either [2]:

- Option 1: equalise the stiffness and rail deflection of the ballasted and non-ballasted tracks, by controlling the resilience of the rail on the non-ballasted track; or,
- Option 2: provide a gradual increase in the stiffness of the ballasted track to match that of the non-ballasted track.

Track stiffness \(k\) is the resistance to deflection \(y\) when subjected to a vertical load \(P\). Its generalised measure (force per unit length of rail per unit deflection) is ‘track modulus’ with a unit, MPa (1 Pa = 1 N/m\(^2\)). Track modulus \(u\) could be expressed in the MPa unit of newton force required to cause a 1-mm length of track to deflect 1 mm. Note that 1 MPa = 145.038 lb/in\(^2\). The relationships between track stiffness and track modulus are as follows:

\[
k = \frac{P}{y} \quad \text{(1)}
\]

\[
u = \frac{k^{4/3}}{64EI}^{1/3} \quad \text{(2)}
\]

where \(k\) is track stiffness (global track resistance), \(E\) is the rail modulus of elasticity and \(I\) is the rail moment of inertia. Table 1 shows typical track modulus ranges for tracks [2, 3, 4]. It is clear that there exists a significant discrepancy of stiffness between conventional railway track systems and railway tracks on a bridge or a viaduct. The poor construction at the bridge ends, which were often the case [3], will exacerbate such stiffness difference and will result in a rapid physical degradation of track support at the bridge approaches [5, 6].
Table 1  Typical track modulus [2-4]  

<table>
<thead>
<tr>
<th>Track Type</th>
<th>Typical Modulus Range (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber sleepered tracks</td>
<td></td>
</tr>
<tr>
<td>ROA (1991) suggests:</td>
<td></td>
</tr>
<tr>
<td>42kg rail + timber on 150mm ballast</td>
<td>5 to 7</td>
</tr>
<tr>
<td>42kg rail + timber on 300mm ballast</td>
<td>7 to 8</td>
</tr>
<tr>
<td>42kg rail + timber on 600mm ballast</td>
<td>8 to 10</td>
</tr>
<tr>
<td>A study shows (Ahlf, 1975):</td>
<td></td>
</tr>
<tr>
<td>Good timber on 150 mm ballast</td>
<td>20</td>
</tr>
<tr>
<td>Good timber on 300 mm ballast</td>
<td>28</td>
</tr>
<tr>
<td>Good timber on 450 mm ballast</td>
<td>35</td>
</tr>
<tr>
<td>Concrete sleepered tracks</td>
<td></td>
</tr>
<tr>
<td>Track on ballast top concrete bridge</td>
<td>25 to 41</td>
</tr>
<tr>
<td>Concrete track on ballast top concrete bridge</td>
<td>&gt; 70</td>
</tr>
</tbody>
</table>

A common practice in track renewal is to establish the transition zone. In contrast, maintenance of existing track infrastructure has limitations of work scope and time allowed. As a result, many bridge end improvement methods become unsuitable and impractical. This paper presents a new idea of using ballast glue/bond to temporarily apply to bridge ends to soothe the dynamic effects. The method provides a short-term maintenance strategy, which is aimed at reducing the track settlement and extending the interval duration of track resurfacing (tamping work).
2 Application of ballast glue/bond

2.1 Case study and its rationale

It is a common understanding that the metropolitan environments in which rail systems operate require quick, rapid repair and maintenance because of very short timeframes and costly track possessions. Accordingly, the stiffness transition management of using ballast bond/glue becomes suitable to such busy environments. A trial of using ballast glue to improve bridge end systems were planned and later carried out at a railway transom bridge at Windsor NSW, which were previously reported of a poor surface condition at both of its bridge approaches. Figure 1 shows the bridge configuration. The location of the bridge allows one to flexibly implement this trial. The straightness of the bridge ensures that the lateral force on the bridge ends does not have a significant influence on this test result.

It should be noted that, over this bridge, a train will accelerate from 105 km/h to 115 km/h on the down direction to the country side; whilst it will decelerate from 115 km/h to 60 km/h on the up direction toward city. Both bridge approaches were improved by using ballast glue/bond. Because of track access difficulty and limitation of sensors, only the city end of the bridge was instrumented with accelerometers to measure and monitor vibration responses.

The railway bridge is a tansom-top mounted on the steel girders. Each structural steel girder spans over 12m and there are 24 spans. It was reported that the bridge transoms were renewed in 2010/2011 whilst the bridge ends were not rectified at the time. It was also noted that only concrete re-sleepering work was carried out at each end during the renewal, without any ground improvement of subgrade or formation. Medium duty fast-clip concrete sleepers were used at both ends of track systems.

Although there were major upgrade works on the bridge and its ends, the top of rails (vertical unevenness) at both ends were found to be outside the operating maintenance tolerances (base operating conditions: BOCs), causing a poor ride comfort [1]. Figure 2 shows the condition of bridge end (city end) before implementing the ballast glue method.

Figure 2 shows that at the city end of the bridge, there were signs of exacerbating vibrations. The ballast wear and pulverisation could be observed. A damage of the insulator of fast clip on the sleeper could also be noticeable.
Figure 2 Conditions of Chain of Ponds Bridge End (City End)
### 2.2 Implementation of Ballast Glue/Bond

Both bridge ends were tamped by a tamping machine in order to adjust and correct track surface before applying ballast glue/bond. Dynamic stabiliser was not used at these locations due to a structures issue. The MC-ballastbond 70 was used for this trial. The ballast bond has a structural design life of 50 years. Figure 3 shows the schematic diagram of the area for ballast glue/bond. The ballast glue was sprayed over the full shoulder for six bays of sleepers, and then half shoulder for the next six bays, then only sleeper length for the next six bays, and the last six bays by half sleeper length. Figure 4 shows the finished work.

![Figure 3 Schematic diagram of ballast glue application](image)

![Figure 4 Ballast glue work at the city end of the bridge](image)
3 Field measurements

Vibration measurements were carried out at two stages, initial condition (pre-ballast glue), and after-trial condition (post-ballast glue). The tests will allow benchmarking the dynamic performance of the bridge ends and evaluation of the effectiveness of the ballast glue method.

Seven locations were equipped with 14 accelerometers. Figure 5 shows the locations of sensors with respect to the track and bridge location with respect to the points of interest. The track was inspected and it was in good condition without major cross level defect [7].

Figure 5 Instrumentation for vibration performance monitoring with respect to train-track interaction points of interest
4 Results and Discussion

The vibration measurements were carried out for up and down directions. The different impact on the bridge end can be observed. Figure 6 shows the vibration responses of the bridge end for down direction due to a passenger train (K83).

Figure 6 Bridge end vibration due to a train K83 down direction (77 km/h)
Figure 6 Bridge end vibration due to a train K83 down direction (77 km/h)
Figure 6 Bridge end vibration due to a train K83 down direction (77 km/h)
Figure 6 shows a selected set of systems performance of the bridge end before applying the ballast glue/bond. Based on a number of repeated data sets, the down direction results indicate a common dynamic behaviour. When the down direction trains run over the bridge end toward the bridge, the trains excite the bridge and the bogie effect triggers the impact vibration on the bridge approve (as noted that the highest impact occurs at the third sleeper from the bridge end – see data consistency at Locations 2 and 4).

The frequency analysis shows that the excitation is sweeping over a high frequency range. The structural dominant frequencies include 560 Hz (associated with the third bending mode of medium-duty sleepers) and 440 Hz (associated with the second bending mode). These excitations will generate resonance at the bridge approaches, causing excessive ballast wear and track settlement. It is noted that the low frequency vibration about 60-70 Hz can also be observed. This is a rigid body mode of vibration, meaning that the track as a lumped structure moves freely up and down (unattached to ballast) to damage the ballast and formation.

Figure 7 shows the comparison of averaging peak vibration magnitudes at the bridge end before and after the application of ballast glue/blond. Recalling that Location 3 is at the last sleeper on track and Location 4 is at the first transom on the bridge. It is found that the ballast glue changes the dynamic track characteristics. The
maximum amplitude of vibration of rail at the bridge end tends to significantly increase due to ballast adhesion (see Figure 7a), whilst the vibration amplitude of sleeper at the bridge end surprisingly remains at the same level. It is noted that the rail vibration levels at the bridge end are in a similar range with those over the bridge.

**Figure 7** Comparative dynamic responses of bridge end

a) rail’s peak vibration at bridge end

b) sleeper’s peak vibration at bridge end
At Location 3 (at the last sleeper on track), it is noticeable that the sleeper is damped by the ballast cohesion. The vibration suppression level is very high as the dynamic effect of larger lumped mass attached to sleeper is pronounced. Also, the duration of sleeper’s vibration spectra is shortened due to ballast glue as illustrated in Figure 8.

![Comparative frequency responses of rail vibration at bridge end](image)

**Figure 30** Comparative frequency responses of rail vibration at bridge end

### 5 Concluding Remark

Based on the vibration test measurements, it is evident that the ballast glue can help suppress the vibration of sleepers and ballast at the bridge approaches in a short term. It can be seen that the dynamic performance of the substructure has been improved but the ballast-glue implementation slightly undermines acoustic characteristics of track (high frequency vibration above 1000 Hz – i.e. increase high-frequency rolling noise or lateral coupling wheel-rail interface noise).

Long-term strategy cannot be determined at this stage but continued monitoring will help justify the maintenance strategy at the bridge ends. Recent data [7] shows the improvement of the bridge ends in terms of reduced track settlements and the stability of track surface geometry.
6 Acknowledgments

The author would like to thank RailCorp for permission to use the track data. The support from P Nguyen (Civil Maintenance Manager) is gratefully acknowledged. Data analysis, structural dynamic analysis and paper preparation work was carried out during the fellowship of the first author at Department of Civil and Environmental Engineering (CEE), Massachusetts Institute of Technology (MIT), Cambridge MA, USA. Technical advice and comments from Professor Herbert H Einstein (CEE, MIT) are gratefully acknowledged.

7 References