FIELD PERFORMANCE TO MITIGATE IMPACT VIBRATION AT RAILWAY BRIDGE ENDS USING SOFT BASEPLATES

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Abstract

The current state of bridge ends and transition zones in railway industry around the world calls for a new and innovative way of design and utilisation of essential components that can automatically combat large dynamic settlements at the stiffness interface. Railway bridge approaches or bridge ends often suffer from a combination of dynamic wheel/rail interaction and poor formation compaction due to construction difficulties at the location, resulting in an initial short-wavelength track settlement at the first few sleeper bays near the bridge over a short period under revenue services. This settlement then further induces impact loading that aggravates differential track settlements. The differential settlement problem at these locations has incurred expensive and frequent maintenance at the areas, causing downtime or restricted railway operation; and importantly more frequent maintenance, which is costly and time-consuming. A collaborative research investigating field performance of the novel component to soften rail elasticity has been carried out. This research demonstrates an application of special soft baseplates and fastening systems to isolate the coupling dynamic actions transferring between transom steel bridge and the ballasted track at the bridge ends. Field measurements were conducted before and after the installation. The results provide strong evidence that the baseplates can filter dynamic impact content from the aggressive loading conditions and provide longer-wavelength load redistribution over railway track infrastructure. This paper highlights field performance of railway bridge ends, which have been upgraded by the soft baseplates and fastenings. It shows that lesser vibration contents are transferred to ballast and granular layers, reducing the risk of differential settlement and ballast dilation.

Keywords: railway bridge end, railway maintenance, bridge approach, soft baseplates, soft fastening systems, dynamic responses, vibration suppression, track-bridge systems.

1. Introduction

Railway bridge ends and transition zones around the world suffer from the differential settlements due to high-intensity dynamic impact load conditions generated at wheel and rail interface [1-4]. The impact load induced by train-track interaction can then exacerbate structural integrity of track components such as ballast, fastening system, sleepers and rails. The differential settlement of rail tracks at these locations can also lead to poor ride quality and high stress threshold on train bogies and train couplers. Importantly, the cumulative damage can undermine the safety of passengers. Accelerated track geometry deterioration at bridge ends often prompts rail authorities and rail
infrastructure manager to provide more frequent maintenance, which is costly and time-consuming. If such the task is unplanned, its associated costs can be three to four time more expensive than those in a master schedule [5-8]. Track geometry deterioration accelerates due to high dynamic loading from the difference of stiffness between open track and rigid bridge [9-11]. Figure 1 shows the track modulus difference at a railway bridge [9]. Although there have been considerable attempt to construct smoother transition zones using different methodologies [12-19], track geometry deterioration still impairs the ability of the railway bridge ends to provide high-quality ride comfort, especially under heavier axle, more frequent and/or higher speed train operations. At the bridge ends, field data shows that the voids and pockets underneath sleepers can often cause further damages to track components. These void and pocket are caused by the permanent sets from ballast deformation, densification and breakage. It has been observed in the field that the void and pocket can be as deep as 50mm or more, prior to track resurfacing. There are several practical solutions recommended in engineering standards, codes of practice and design guidelines by railway authorities around the world. An example is ESC 310 Underbridge in Australia, which promotes a variety of solutions suitable for different type of stiffness transitions such as transom bridge-track, viaduct-track, turnout-track, etc. Such the variations also depend largely on the constructability and maintainability to suit either brown-field situations of renewal or construction work at a particular location [20-22].

![Figure 1 Bridge-track system and relative track modulus [9]](image)

One key criterion for the stiffness transition is to smooth the stiffness interface between the dissimilar track types. Feasible practical design options are to establish the transition to either: Option 1: equalise stiffness and rail deflection of the ballasted and the non-ballasted tracks, by controlling the resilience of the rail on the non-ballasted track; or, Option 2: provide very gradual change in the stiffness of the ballasted track to match that of the non-ballasted track. In general practice, track stiffness \( (k) \) is the resistance to absolute rail deflection \( (y, \text{right underneath the load}) \) when subjected to a vertical load \( (P) \).
Its generalised measure (force per unit length of rail per unit deflection) is referred to as ‘track modulus’ with a unit, MPa (1 Pa = 1 N/m² and 1 MPa = 145.038 lb/in²). The 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. The Bernoulli-Euler relationship between track stiffness and track modulus is as follows:

$$k = \frac{P}{y}$$  \hspace{1cm} (1)

$$u = \frac{k^{4/3}}{(64EI)^{1/3}}$$  \hspace{1cm} (2)

where $k$ is track stiffness, $E$ is the rail modulus of elasticity and $I$ is the rail moment of inertia. Table 1 shows typical track modulus ranges for tracks. Note that the track modulus also depends on the type of other resilient track components (i.e. sleeper material rigidity, rail pads, ballast, and formation). It is clear that there exists a significant difference of stiffness between conventional railway track systems and railway tracks on a bridge or a viaduct.

Table 1 Typical track modulus [4-5]

<table>
<thead>
<tr>
<th>Track Type</th>
<th>Typical Modulus Range (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber sleepered tracks</td>
<td>5 to 25</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>25 to 41</td>
</tr>
<tr>
<td>Track on ballast top concrete bridge</td>
<td>55 to 83</td>
</tr>
<tr>
<td>Concrete track on ballast top concrete bridge</td>
<td>&gt; 70</td>
</tr>
</tbody>
</table>

The stiffness difference, train speeds, mass and suspension characteristics of train define the magnitude of the impact force generated at the interface. The poor construction at the bridge ends, which were often the case especially in North America [6], will exacerbate such stiffness difference and will result in a rapid physical degradation, wear and breakage of track support components at the bridge approaches [23-24]. A study in the UK has shown that if the track has deteriorated (when the track formation fault occurs), the wheel rail interaction tends to be increasing [6]. The dynamic effects depend dramatically on train speeds. It is found that the deteriorated bridge ends can also cause rough riding of trains and the wheel/rail dynamic force can be increased significantly.

A common practice in construction and renewal of new or existing railway bridges is to establish a transition zone. In contrast, maintenance activity of existing, aging track infrastructure is restrained considerably by work scope, confined space and the allowed possession time [7-14]. As a result, many new methods for railway bridge end improvement requiring subgrade and subballast layer modifications become unsuitable and impractical, especially for aging or heritage railway bridges. In this study, we have adopted the first design option in order to establish equal rail displacement along the track over a railway bridge extent to adjacent open plain tracks. This paper highlights the field performance and dynamic behaviours of a railway transom bridge and its approaches installed with special soft baseplates and fastening systems in order to improve isolation of the coupling dynamic interaction transferring between transom steel bridge and the ballasted track at the bridge ends.

This paper is aimed at demonstrating the practical benefits of this design option for both green- and brown-field construction and maintenance projects [25-26]. The field tests have been conducted at a railway bridge in south coast of New South Wales, Australia. The track geometry data was derived from a track inspection vehicle for detailed evaluations. Based on the field measurements and on-board monitoring, the upgraded bridge end improvement method can be investigated for the effectiveness. The data analysis of track geometry data from the track inspection vehicle ‘AK Car’ will be used for displaying track deterioration rate at the railway bridge ends [27]. We hope that this paper will provide
sufficient evidence to support this alternative method for bridge end improvement, which will be suitable for many critical situations in railway construction practice.

2. Railway transom bridge

Field inspections of railway track and railway steel bridge in south coast of NSW, Australia have led to a prioritised maintenance and renewal of its transoms and track support. Figure 3 shows structural condition of timber transoms before the bridge renewal. This poor structural integrity of the transoms has prompted a serious consideration for redesign of the track support structure and materials. Since the bridge approaches are laid on curves, using ballast bonding [2] could prevent the flexibility and resilience for routine track maintenance to adjust track superelevation (or cant). On this ground, alternative bridge end improvement is needed.

The bridge has been designed for transom renewal using fibre reinforced foamed urethane (FFU) transoms to improve the bridge’s life cycle, durability and service life. To mitigate structural-bourne noise from the railway steel bridge and to suppress vibration at the bridge ends, the special vibration isolation fastening systems (ALT1 baseplate) has been adopted on top of the FFU transoms as the fastening system. Both bridge approaches were designed to improve the transfer zone using geocell stabilisation technique and also the extension of vibration isolation systems. The construction was done in late November 2012. Figure 4 shows the construction processes and condition after the construction.

Figure 3 Condition of old timber transoms (after 20 years)

Figure 4 Reconstruction of railway transom bridge [23-24]
In general, a bridge is designed with specific structural parameters such as span length, support condition, combined use of materials, and many others. These design parameters generally result in the uniqueness of a railway bridge. However, track components (such as rail, fastening systems, sleepers, etc.) are often chosen for compatibility in systems requirements. The use of soft baseplates in combination with FFU sleepers and geogrid formation portrays an interesting practice. FFU transoms (bridge sleepers) were designed to mimic engineering properties of timber transoms, and the geogrid was used to strengthen a lower soft formation. On this ground, such change does not contribute significant intermediate effects on impact vibration mitigation. Consequently, the observation in this study displays the mere performance of soft baseplates in mitigating impact vibration at bridge ends.

3. On-board monitoring

Track recording data is the track geometry data obtained from an inspection vehicle (as shown in Figure 7). The accuracy, repeatability and quality of the data depend largely on measurement method, sensor and instrumentation, train speed, and location identification [28]. In this case study, the track inspection vehicle has been installed with axle-box accelerometers. The inertia data is then computed to provide track maintenance engineers with geometry data. The geometry data, which had been recorded using ‘AK Car’ Geometry Recording Vehicle, illustrates fundamental dynamic track parameters (top, line, gauge, cross level and twist) in each stage of rail track’s life cycle. The AK car’s top 10m data can demonstrate that the track surface of bridge end has been improved by the reconstruction as shown in Figure 5. From Figure 6, it is also found from further data analysis that using this bridge end improvement method, the deterioration of the bridge ends is rather slow:

Figure 5. Geometry data along the bridge before and after reconstruction.
4. Field pass-by measurements

Field performance of the bridge end improvement method can be evaluated by operational pass-by measurements. Figure 7 shows the instrumentation of accelerometers at fibre-reinforced foamed urethane (FFU) transoms, Flat1 special sleepers (with ALT1 baseplates), stiffness transfer sleeper (with SA-47 pads), and ordinary sleepers.

5. Results and discussion

The field data consists of vibration data of rails and sleepers/transoms, and noise level at the bridge end. A total of 12 data sets were recorded from the revenue operations. Note that this is the bi-directional track. In this analysis, 3 representative sets of data will be presented. Figure 8 shows the field data on the down direction (the bridge end acting as the entrance end).
a) on the bridge  b) at the bridge end

Figure 8 Field data on the entrance end (down direction)

c) at the guard rail sleeper  d) FLAT1 sleeper

Figure 8 Field data on the entrance end (down direction)
The field data shows that the vibration improvement at the bridge ends can be observed. Significant vibration isolation can be seen from Figure 9 as the ballast vibration magnitude has been suppressed.

6. Conclusion

Transition design of railway bridge ends is crucially critical, even though its construction is difficult in practice. These areas are often prioritised for more frequent track maintenance in comparison with that of open plain tracks. Especially for heavy freight traffics and for high-speed train operations, the degradation rate of track geometry and performance is amplified by the dynamic effects. There are many possible solutions to this problem in practice recommended by both public and private rail sectors. Nonetheless, track and rail engineers must consider and evaluate suitability of each solution on a case-by-case basis. This is because railway infrastructure has a wide variety of components, structural systems and design principles. Systemic compatibility, maintainability and constructability are the key criteria for design selection. In this study, the utilisation of special soft baseplates and their fastening...
systems have been evaluated. This method improves vibration isolation characteristics of track to bridge and track to formation at the bridge ends. Based on the field vibration measurements, it is apparent that the vibrations insignificantly transfer from the rails to sleepers and from sleeper to the ballast layer. Although the bridge end vibration isolation has been significantly improved, the geometry data from the track inspection vehicle ‘AK Car’ shows that a slow deterioration process at the bridge end continues. Even though this rate of settlement is much less than the other cases, this prompts a monitoring scheme for the integrity of bridge ends and its components to be implemented in a regular manner.

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