Braking/Traction Assessment for Railway Bridge to AS5100:2017

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Outline

1. Why research undertaken on Braking and Traction?
2. What changed in the new code?
3. The rational method
4. Track-Bridge Interaction Analysis
5. Thermal load
6. Conclusion
Longer, Heavier, Faster Train $\rightarrow$ Larger forces on bridges
What is Braking and Traction (B/T)

- Longitudinal forces generated by the Train.
  - Braking → Stop the train
  - Traction → Start or Speed up the train
Background

- Rockfield started some project using 2004 code, switched to the new code in the middle of project.
- Significant changes and improvements for B/T on Rail bridges in the new code.
- The assessment effort increased
Rockfield undertook structural assessment for 12 railway bridges in QLD.

They are all open deck steel truss bridges.

B/T force is critical for the load rating.
B/T Critical for these trusses
Rockfield reviewed a few U-Frame railway bridges in WA.

- Under-estimated longitudinal bearing loads.
- Bearing Issues
Study and Research Required

B/T is important for: bearings; piers and even superstructure

- Underestimating → unsafe design
- Overly conservative → Higher cost for asset owners

→ Accurate Assessment for B/T is highly desired
Study and Research Required

- No experience in this new code
- No commentary for the new code.
- No guide on Rational Method
- No Experience on Track-Bridge interaction.

→ Study and research required to assess B/T accurately.
Limitations.

- We are Consulting Engineers. This study and research was undertaken while working on the projects with limited time and budget.

- The method developed here is for the particular bridges we have completed. → May not be suitable for all bridges → should be used as a guide only.
1.5 REFERENCES

<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
</tr>
</thead>
</table>
2. CHANGES TO AS 5100:2017

1. Empirical and Rational methods.
2. Separation of B/T forces.
3. Magnitude of B/T forces.
4. Load distribution assessment.
5. Track-Bridge interaction considerations.
Empirical Method Equations

**AS5100.2: 2017**

**Braking forces**: eq 9.7.2.2(1)

\[ \text{BF} = 200 + 15L_{LF} \]

**Traction forces**: eq 9.7.2.2(2) to (4)

\[
\begin{align*}
\text{TF} &= 200 + 25L_{LF} \quad \text{for} \quad L_{LF} \leq 25 \text{ m} \quad \ldots 9.7.2.2(2) \\
825 + 15(L_{LF} - 25) &= 25 \text{ m} < L_{LF} \leq 50 \text{ m} \quad \ldots 9.7.2.2(3) \\
1200 + 7.5(L_{LF} - 50) &= 50 \text{ m} < L_{LF} \leq 250 \text{ m} \quad \ldots 9.7.2.2(4) \\
2700 + 5.0(L_{LF} - 250) &= 250 \text{ m} < L_{LF} \quad \ldots 9.7.2.2(5)
\end{align*}
\]

where

\[ \text{TF} = \text{longitudinal traction force, in kilonewtons} \]

\[ L_{LF} = \text{total length of the bridge, in metres} \]

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**Table 8.6.2**

<table>
<thead>
<tr>
<th>Track type</th>
<th>Loaded length (L) m</th>
<th>Horizontal force kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discontinuous</td>
<td>All</td>
<td>200 + 20L</td>
</tr>
<tr>
<td>Continuous</td>
<td>( L &lt; 50 \text{ m} )</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>( L &gt; 50 \text{ m} )</td>
<td>( 100 + 15(L - 50) )</td>
</tr>
</tbody>
</table>

---

Longitudinal Braking/Traction and Thermal force Assessment for Railway Bridge to AS5100:2017
Comparison (2004 Continuous Track vs 2017 Empirical Method)

Braking: A constant **850 kN increase** for bridges > 50m.

Traction increased greatly for bridges <150 m

<table>
<thead>
<tr>
<th>Bridge Length (m)</th>
<th>Braking Force (kN)</th>
<th>Traction Force (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>100</td>
<td>500</td>
</tr>
<tr>
<td>40</td>
<td>100</td>
<td>800</td>
</tr>
<tr>
<td>60</td>
<td>250</td>
<td>1100</td>
</tr>
<tr>
<td>80</td>
<td>550</td>
<td>1400</td>
</tr>
<tr>
<td>100</td>
<td>850</td>
<td>1700</td>
</tr>
<tr>
<td>150</td>
<td>1600</td>
<td>2450</td>
</tr>
<tr>
<td>200</td>
<td>2350</td>
<td>3200</td>
</tr>
<tr>
<td>500</td>
<td>6850</td>
<td>7700</td>
</tr>
</tbody>
</table>
# Empirical & Rational Methods Comparison

<table>
<thead>
<tr>
<th>Methods</th>
<th>Empirical</th>
<th>Rational</th>
</tr>
</thead>
</table>
| Force distribution to outside of bridge | • The calculated force taken by the bridge only.  
• Distribution beyond the bridge has been considered in the equations. | • The distribution beyond the bridge should be assessed.    |
| Track Model Extent            | The track for the extent of the bridge deck only.                          | The track on the bridge and 100 m beyond bridge             |
| Rail Traffic Load on tracks   | Fully loaded tracks                                                       | Partial loaded track allowed                                |
| B/T Force Calculation         | **Equations** provided                                                    | **first-principles** using train spec                       |
| **Summary**                   | • Calculation simpler  
• not accurate for particular trains                                        | • **More accurate**  
• more calculations  
• more train information needed                                              |
3. The Rational Method

Our Focus ➔ How to calculate the B/T using this method
Train specs, including:

- Length and axle spacings.
- Axle loads.
- Loco configuration
- Traction acceleration.
- Braking deceleration or stop distance.
- Vehicle combinations
Train information

Example

Figure 8.1.1 – Dimensions and Design Axle Loads for Individual Vehicles
### Train information

**Example: Locom and train configuration**

- For normal pooled fleet train operations (and Train Performance simulations), the standard (2017) train is 3 Locomotives @ 204 tonne + 240 pooled fleet ore cars @160 tonnes gross with banking locomotives (typically 2) where required.

- For the layout design of passing tracks and yards, the design pooled train is 3 locomotives + 240 pooled fleet cars + 3 banker locomotives (Refer Section 8.7).

- Allow an additional 19m for Compressor/Brake Cars in the Yard and Car Dumper track layouts.

- Train lengths for the purposes of track layout design are given below:

<table>
<thead>
<tr>
<th>Train Lengths for Track Layout Design</th>
<th>Train Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Pooled Fleet Train (all new work) w/o bankers (3 Locos + 240 Pooled Cars)</td>
<td>2,310 m</td>
</tr>
<tr>
<td>Design Pooled Fleet Train (all new work) with bankers (3 Locos + 240 Pooled Cars + 3 Locos)</td>
<td>2,380 m</td>
</tr>
<tr>
<td>Design Pooled Fleet Train Port (all new work) with C/B Cars (3 Locos + 240 Pooled Cars + C/B Cars)</td>
<td>2,329 m</td>
</tr>
</tbody>
</table>
### “B/T Calculation Parameters” example

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Length</th>
<th>Traction acceleration</th>
<th>Traction length$^1$</th>
<th>Braking deceleration</th>
<th>Braking length</th>
<th>Minimum clear distance between trains$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight train</td>
<td>1200</td>
<td>0.5</td>
<td>60+60$^4$</td>
<td>1.5</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>Passenger train</td>
<td>230</td>
<td>1.5</td>
<td>230</td>
<td>1.5</td>
<td>230</td>
<td>300</td>
</tr>
<tr>
<td>Work train$^3$</td>
<td>300</td>
<td>0.5</td>
<td>25</td>
<td>0.75</td>
<td>300</td>
<td>300</td>
</tr>
</tbody>
</table>

1. Traction length is the length of the rail vehicle over which the traction forces are to be applied so as to produce the most adverse effect. These lengths are based on maximum adhesion between the wheels and the rail. Braking forces can be assumed to be applied uniformly over the full length of the vehicle.

2. The specified minimum clear distances between trains are intended to be used only for the purpose of determining the positioning of longitudinal rail traffic forces for structural design purposes.

3. The parameters for the work train were derived for a ballast hopper wagon.

4. The 120m traction length is to be split equally between front and rear of a push-pull operation.
The Rational Method – theory behind

Newton’s Second Law applied on the train in the longitudinal direction as:

\[ \sum F = M \cdot a \]

- \( \sum F \) is the total longitudinal forces acting on the train in kN
- \( M \) is the total mass of the train in tonne
- \( a \) is the longitudinal acceleration or deceleration of the train in m/s\(^2\)
The Rational Method – forces on the train

- $\sum F$ is the total longitudinal forces acting on the train

$$\sum F = Ft + Fr$$

- $Ft$ is the braking or traction force.

- $Fr$ is the train passive resistances including:
  - Aerodynamic drag
  - Wheel rolling resistances
  - Resistances to the train’s forward motion on gradients
  - Resistances to the train’s forward motion on curves.
B/T Limited by Friction

B/T Force is developed & **limited** by the friction between **wheels and rail**;

- **Ff = N × μ**
  - Ff = friction force, in kN
  - N = Train or Locomotive weight, in kN
  - μ = Coefficient of Kinetic friction between rail and **moving wheels**.
Friction Coefficient

\[ \mu = \frac{\mu_0}{1+0.01V} \quad \text{or} \quad \mu = \mu_0 \left( \frac{33}{42+V} + 0.21 \right) \]

- \( \mu \) = Kinetic friction coefficient between rail and moving wheels.
- \( \mu_0 \) is the static friction coefficient between the rail and the wheel can be taken between 0.30 to 0.45.
- \( V \) is the speed of the train in km/h

For braking, \( \mu = 0.13 \) to 0.23 for 100km/h speed, may adopt \( \mu = 0.2 \).

For traction, speeding the train up from 0 is normally critical. \( \mu = \mu_0 \), Adopt 0.45 (0.5 recommended by some Rail Authority)

<table>
<thead>
<tr>
<th>Authority</th>
<th>Rail vehicle</th>
<th>( \mu_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNCF (France)</td>
<td>Electric monophase locomotives, multimotor bogies</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>Electric monophase locomotives, monomotor bogies</td>
<td>0.35</td>
</tr>
<tr>
<td>DB (Germany)</td>
<td>Diesel locomotives</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>Electric monophase locomotives</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>Diesel locomotives</td>
<td>0.22 – 0.29</td>
</tr>
<tr>
<td>RENFE (Spain)</td>
<td>Classic electric locomotives</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>Modern electric locomotives</td>
<td>0.31</td>
</tr>
<tr>
<td>USA</td>
<td>SD75MAC diesel and electric locomotives</td>
<td>0.45</td>
</tr>
<tr>
<td>AUSTRALIA</td>
<td>AS 5100.2 Supp 1—2007</td>
<td>0.3 -0.4</td>
</tr>
</tbody>
</table>
Traction force

1. Total required traction force \( Ft = M \cdot a \) (\( M \) is the train mass)

2. Achievable friction from one loco & \( \mu_0 \),

\[
F_f = N \times \mu_0 \\
\text{(N is the Loco weight)}
\]

3. Check \( Ft \) and \( F_f \) to determine if the loco number provided is acceptable.

4. Final Traction force for load distribution analysis on the bridge

\[ Ft = \text{(number of locos considered)} \times F_f \]
Components to be considered for distribution analysis

- Rail
- Ballast and transoms
- Bearings
- Superstructures
- Piers and abutments, foundations.
- Thermal, S&C of concrete superstructures
4. B/T DISTRIBUTION ANALYSIS

- Normally use model to determine the forces distribution

Train–Track–Bridge

Full dynamic interaction model NOT Required

We need more simplified models.
THE ANALYSIS MODEL INCLUDING Track-Bridge interaction

Model including 3 parts:

1. **Bridge structure**
2. **Track**
3. **Connections in between**
Bridge structure model

All relevant structural components should be modelled. the following should also be included:

- The bending stiffness of the superstructure
- The vertical levels of track/deck/girders/bearings.
- The substructure
- Transoms should be modelled for open deck bridge.
Superstructure bending stiffness

- Girder vertical deformation generates interaction forces.
- Longitudinal interaction force caused by the vertical traffic load should not be neglected.
Instrumentations on Superstructure

- Rockfield have identified high axial force in the main girders due to vertical traffic loads through strain gauge.

The strain in the top flange is 80 microstrain larger than the bottom flange.
Piers and Abutments

The following displacements to be considered for stiffness:

- Pier bending
- Footing rotation
- Horizontal sliding
Piers and Abutments

- **Separate models** to determine their stiffness → apply as spring supports in the main model.
- Usually, **sensitivity** analysis required on foundation stiffness.
- Bridge **abutment** stiffness for loads towards and away are different.
- The soil reacts more stiffly under B/T than under thermal
- anchored to the open-deck bridge (Without Ballast)
- buried in the ballast
Fasteners

Fully anchored systems:

- Clamping force preventing rail longitudinal movement
- Good for braking/traction distribution, but bad for thermal.

Zero-toe Anchoring:

- Restrain the rail vertically, not longitudinally.
- Good for thermal, but bad for braking/traction distribution.
BALLAST

- Ballast: ‘stones’ beneath the track
- Not well-defined properties ← Vary: different loading/time/temperature/humidity
longitudinal interaction between Track and bridge

- A **sliding action** between track and bridge. Governed by:
  - The track sliding resistance $k$
  - the relative longitudinal displacement between track and bridge $u$

→ Described as **load-displacement parameter** $k/u$

- **Bi-linear (elastic-plastic) behavior**
**Track load-displacement parameter k/u (International Union of Railways UIC 774-3)**

Ballast bridge → \( k/u \) governed by ballast  
Ballastless bridge → \( k/u \) governed by rail fastener

<table>
<thead>
<tr>
<th>Fastening &amp; Ballast Condition</th>
<th>Track Loading condition</th>
<th>Key</th>
<th>( u_0 ) (mm)</th>
<th>( k ) (kN/m)</th>
<th>Connection stiffness in Elastic Zone (kN/m/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional fastening &amp; Ballast</td>
<td>Unloaded</td>
<td>Key4</td>
<td>2</td>
<td>12</td>
<td>6.0E+03</td>
</tr>
<tr>
<td></td>
<td>Loaded</td>
<td>Key2</td>
<td>2</td>
<td>60</td>
<td>3.0E+04</td>
</tr>
<tr>
<td>Conventional fastening &amp; Ballastless</td>
<td>Unloaded</td>
<td>Key3</td>
<td>0.5</td>
<td>40</td>
<td>8.0E+04</td>
</tr>
<tr>
<td></td>
<td>Loaded</td>
<td>Key1</td>
<td>0.5</td>
<td>60</td>
<td>1.2E+05</td>
</tr>
<tr>
<td>Zero-toe fastening (Ballast or Ballastless)</td>
<td>Unloaded</td>
<td>-</td>
<td>0.5</td>
<td>0</td>
<td>0.0E+00</td>
</tr>
<tr>
<td></td>
<td>Loaded</td>
<td>Key1</td>
<td>0.5</td>
<td>60</td>
<td>1.2E+05</td>
</tr>
</tbody>
</table>

Longitudinal Braking/Traction and Thermal force Assessment for Railway Bridge to AS5100:2017
Analysis Model Types

The importance and parameters of the bridge ➔ Model Types

- Type 1: Simplified separated models for thermal, braking, traction using BEA or FEA
- Type 2: Complete analyses for all loading conditions with step-by-step process using FEA (Strand7, ANSYS and Midas)
Sometimes it is not practical to model large scale or complex bridge with a moving load using the FEA software.

Most of the time, beam element analysis like SpaceGass (SG) software package with care taken, is sufficient for Type 1 Models.
Model the connection between Rail and Bridge in Strand 7.

- The connection can be modelled as beams (connection type or truss type)
- Example model: connection type beam with bi-linear material.
Model connection with linear material in SpaceGass

Modelled as dummy beam elements.

- SG cannot model bi-linear material, but the force in the connection members can be limited below its yield by adjusting the member stiffness.
### Strand 7 vs SpaceGass Results Comparison

For the purpose of longitudinal assessment, the SG results are ACCURATE enough for most of the bridges that only required type 1 analysis.

<table>
<thead>
<tr>
<th>Bearing Load</th>
<th>Train Vertical +Braking(+X)</th>
<th>Train Vertical +Braking(-X)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Assessment method</strong></td>
<td><strong>SG</strong></td>
<td><strong>FEA</strong></td>
</tr>
<tr>
<td>ABUTMENT (-X END)</td>
<td>157</td>
<td>150</td>
</tr>
<tr>
<td>ABUTMENT (+X END)</td>
<td>730</td>
<td>774</td>
</tr>
</tbody>
</table>
Tips to Model Different loading conditions in SpaceGass.

If the braking/traction applied as a **moving axle load:**

- two different stiffness connection members can be modelled at the same location to for **loaded** and **unloaded** condition.
Applying braking and traction force in the model

- Braking - through all axles of the train
- Traction - to locos only.
- Applied to match the train moving scenario to produce the most adverse effect
- Vertical load from the rail traffic should be applied at the same time.
- For bridges with larger “span/axle spacing” aspect ratios → the loads may be applied as UDL over the corresponding length of the train or locomotives.
Example for traction force applied

Train wagons (vertical load only)

Locomotive: vertical and traction load
5. Thermal load

- Thermal load is important

- For type 1 modelling
  - Thermal can be assessed separately
  - Linearly combined with braking and traction.

- Unloaded track stiffness “k” for thermal effect.

- Creep and shrinkage in concrete bridges can be assessed in a similar manner as thermal load.
6. Conclusion

► The evaluation is complicated with consideration of Track-structure interaction.

► Designers and asset owners should be aware of the complexity of these evaluations for planning and budgeting.

► Sensitivities analysis and trial models to determine the suitable analysis method.
Thank you.